DUTY TESTS

OF

TRIPLE EXPANSION PUMPING ENGINES.

1893.

THE EDW. P. ALLIS CO.,

MILWAUKEE, WIS., U. S. A.

NOTE.

The economy shown by these engines has never been equalled by any other engine, of any description or under any conditions. Particular attention is called to the figures for Duty, Steam per I. H. P., and B. T. U. per I. H. P.

THE EDWARD P. ALLIS COMPANY.

NORTH POINT PUMPING STATION, MILWAUKEE, WIS.

REPORT OF TEST

OF

PUMPING ENGINE

AT

MILWAUKEE, WIS.,

NORTH POINT PUMPING STATION.

BY PROF. R. C. CARPENTER,

CORNELL UNIVERSITY, ITHACA, N. Y.

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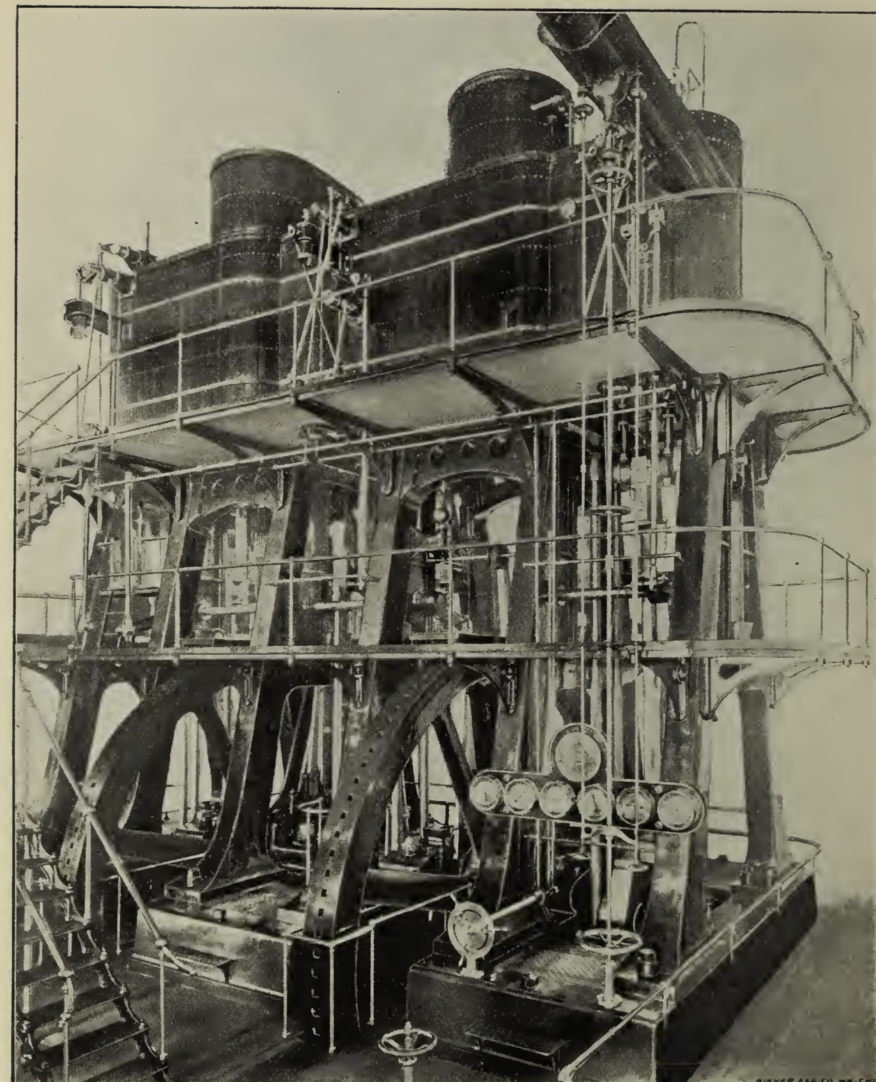


ALLIS TRIPLE EXPANSION PUMPING ENGINE,
NORTH POINT PUMPING STATION.

REPORT OF TEST OF PUMPING ENGINE AT NORTH POINT STATION, MILWAUKEE, WISCONSIN.

BY R. C. CARPENTER, ITHACA, N. Y.

Description of Plant.

The engine tested is a triple expansion, vertical engine with the three cylinders arranged side by side. The engine was built by the Edward P. Allis Co., and designed by Irving H. Reynolds under general supervision of Edwin Reynolds, general superintendent of the Allis works. The general appearance of the engine is well shown in Figure 1, as it appears from the engine-room floor. The pumps are entirely below the floor and the piston rods from the engine are directly connected to the plungers of the pumps. It has two fly-wheels, which are connected to the main shaft, and perform the office simply of aiding in the regulation of the engine. The engines and pumps have in each case five feet stroke, the diameters of the engine cylinders being respectively 28, 48, and 74 inches and are double acting. The diameter of the pump plungers are 32 inches and in each case are single acting. Between each two cylinders of the engine is a large receiver, which is reheated by pipes containing high pressure steam. The volumes of these receivers are respectively, high pressure 101.3 cu. ft., intermediate receiver 151 cu. ft. The engines are in each case steam jacketed, in the high pressure and intermediate cylinders these jackets are supplied with live steam at boiler pressure; but on the low pressure cylinder the jacket is supplied with steam which passes through a reducing valve and which has a constant pressure of 34 pounds. In each case the cylinders are jacketed on both heads and barrel. The steam is supplied to the high pressure jacket by a pipe leading directly from the main steam pipe, the exhaust from this jacket supplies the jacket of the intermediate cylinder and this is led into a trap, the overflow of which

ordinarily passes into the suction of the feed pump for supplying the boilers. The exhaust steam from the low pressure cylinder jacket is similarly received into a steam trap and also discharged into a feed pipe.

The valves of the engine are arranged as follows: The admission valves of all the cylinders are of the Corliss type and operated in the usual manner, so are also the exhaust valves of the high and intermediate cylinders. The exhaust valves of the low pressure cylinder are, however, poppet valves and when closed are flush on the inside of the cylinder head, thus eliminating any clearance due to exhaust ports. All the valve ports are located in the cylinder heads. The governor is of the ordinary fly-ball type with special arrangements for controlling this style of engine. It is connected only to the high pressure cut-off mechanism, and controls the engine only at maximum speed. The other cut-offs are operated by hand mechanism, as is also the high pressure at low speed.

In each engine are two piston rods, which are connected to a cross-head, and this in turn is connected to the pump plungers by four tie rods. The clearances in the different engine cylinders, as given by the makers, are respectively, high pressure, $1\frac{4}{10}$ per cent.; intermediate cylinder, $1\frac{5}{10}$ per cent.; low pressure cylinder, 0.777 of one per cent.

The arrangement of the pumps is shown very clearly by Fig. 2, which gives a plan of engine foundation, position of pumps, position of boilers and arrangement used for supplying feed water. The pumps are located directly beneath the engine cylinders, and are designated by P on the drawing. The valves are located in a cylinder, the position of which is designated by VC on the drawing. The valves for these pumps, instead of being arranged on a single plain surface, are situated on the sides and tops of small hexagonal prisms. The valves themselves are rubber and about four inches in diameter, but their combined area is practically equal to that

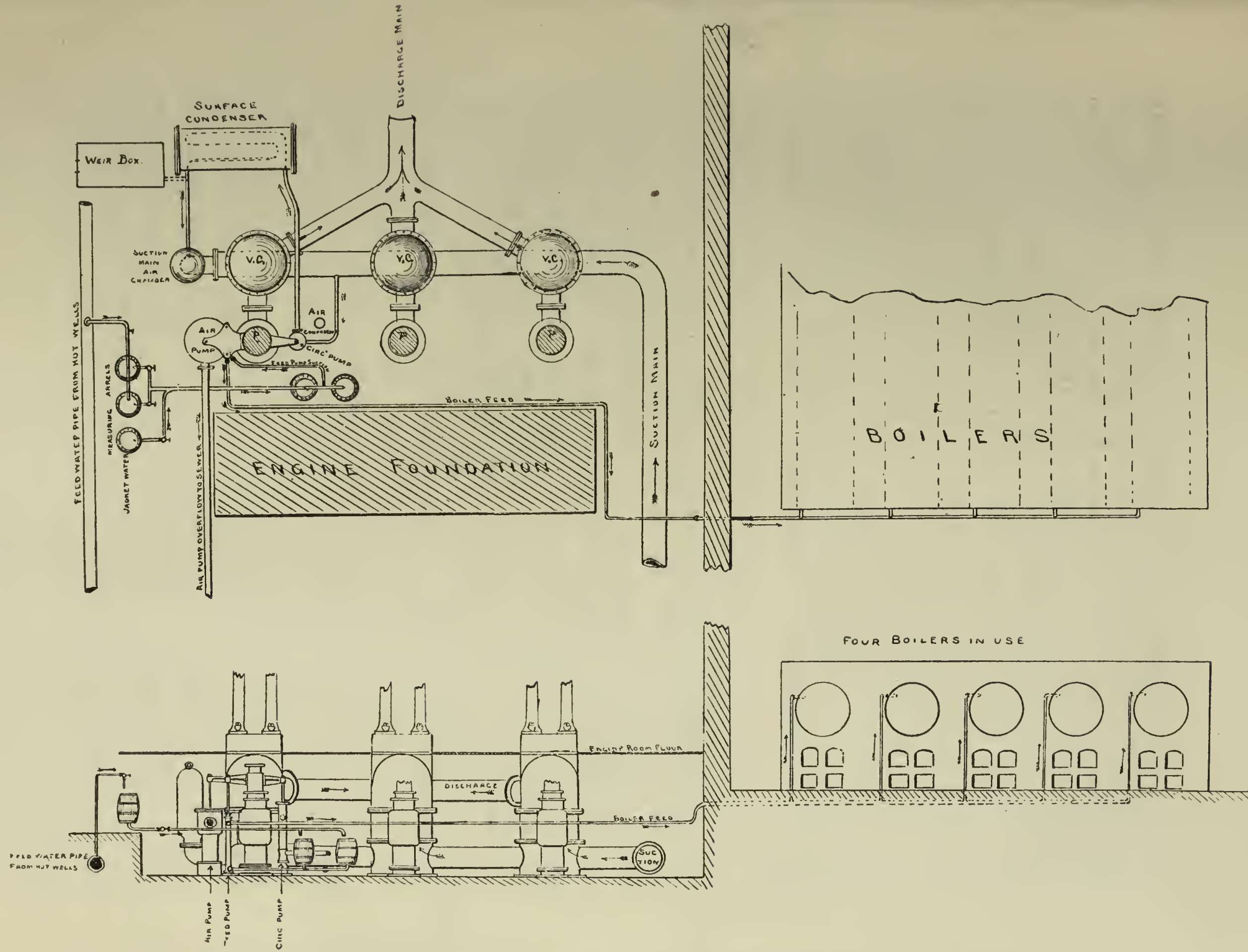
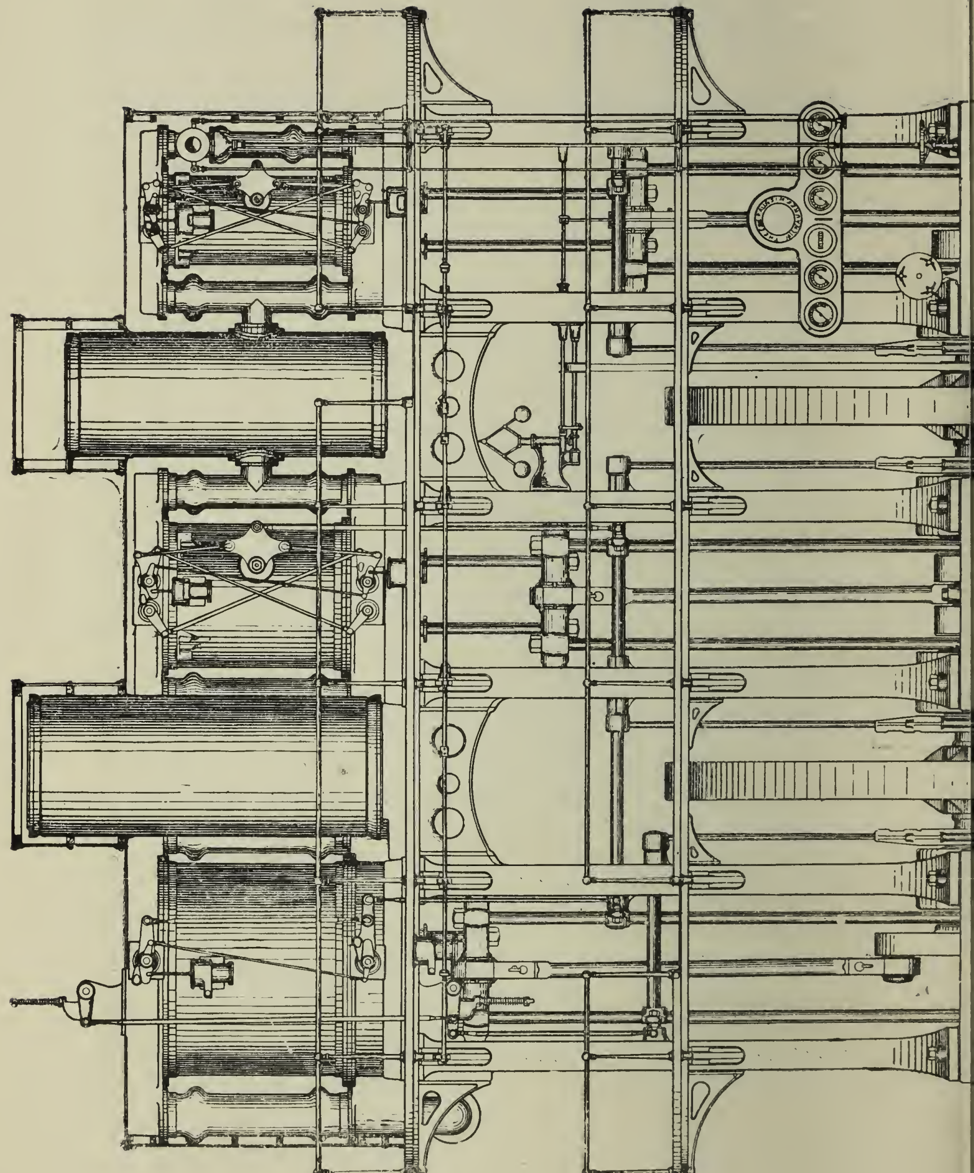


FIG. 2.—GENERAL PLAN SHOWING ARRANGEMENTS FOR TESTING.

of the pump plunger. The water is received into the pump through the lower portion of the valve chamber, passing and lifting the suction valves, it then is, by the reverse motion of the plunger, forced outward and upward past the delivery valves in the upper part of the valve chamber. (Fig. 4.) The water is received into a well which is connected with Lake Michigan by a large masonry tunnel. The bottom of this well is 39.8 feet from the center of the pressure gauge on the main engine-room floor. The center of the valve chamber is 19.8 feet below the same gauge, and during the test the suction lift, from the center of valve chamber to the surface of the water, averaged 10.77 feet. The general arrangement of suction pipe is shown in the drawing, Fig. 2.

The air pump, circulating pump, boiler feed pump, and the pump for supplying the air chambers with compressed air, were all directly connected to the moving parts of the engine, and in each case had the same stroke. The circulating pump supplied the condenser with water, taking it from the suction side of the pump and returning it to the same side after having passed through the condenser. The condenser used was a surface condenser of the Wheeler pattern and was supplied with circulating water, as explained, the object of which was to remove nearly all the pressure from the condenser tubes. The dimensions of all the pumps are given with the data of the test.

The boiler plant, from which the steam is derived for operating the engine, is situated in the adjacent room, as shown in the plan, Fig. 2. The boilers are in each case plain tubular boilers, with fixed grates, constructed by the builders of the engine, The Edw. P. Allis Co. The boilers are five in number, of which four were used during the test. The dimensions of each boiler are given in the annexed tables of the results. The discharge gases from the boiler were carried by a horizontal breeching over the front portion of the boiler to a large brick stack, 125 feet in height.



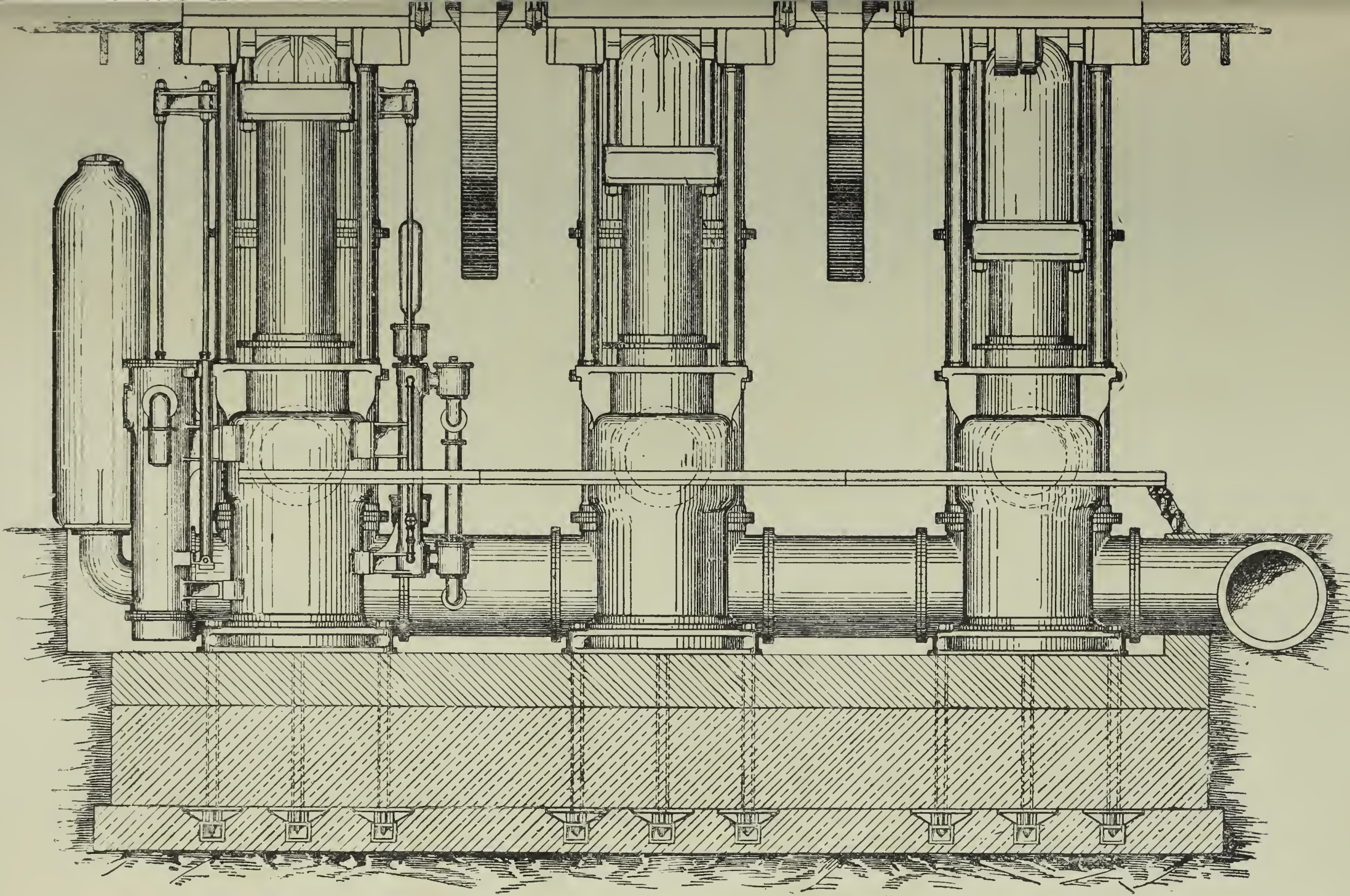
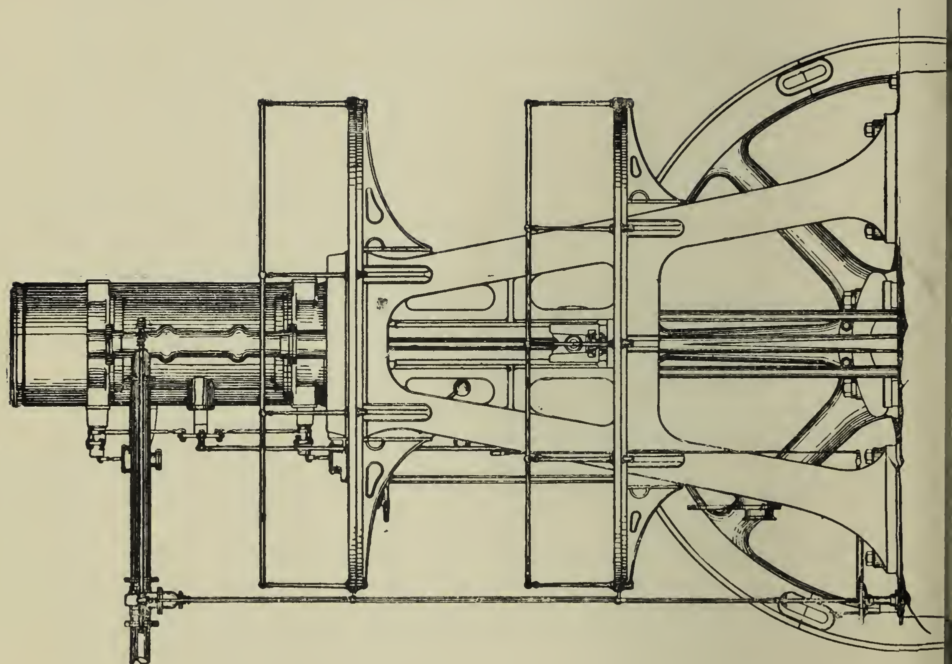


FIG. 3. ELEVATION OF ENGINE AND PUMPS, TRIPLE EXPANSION ENGINE.
North Point Pumping Station, Milwaukee, Wis.



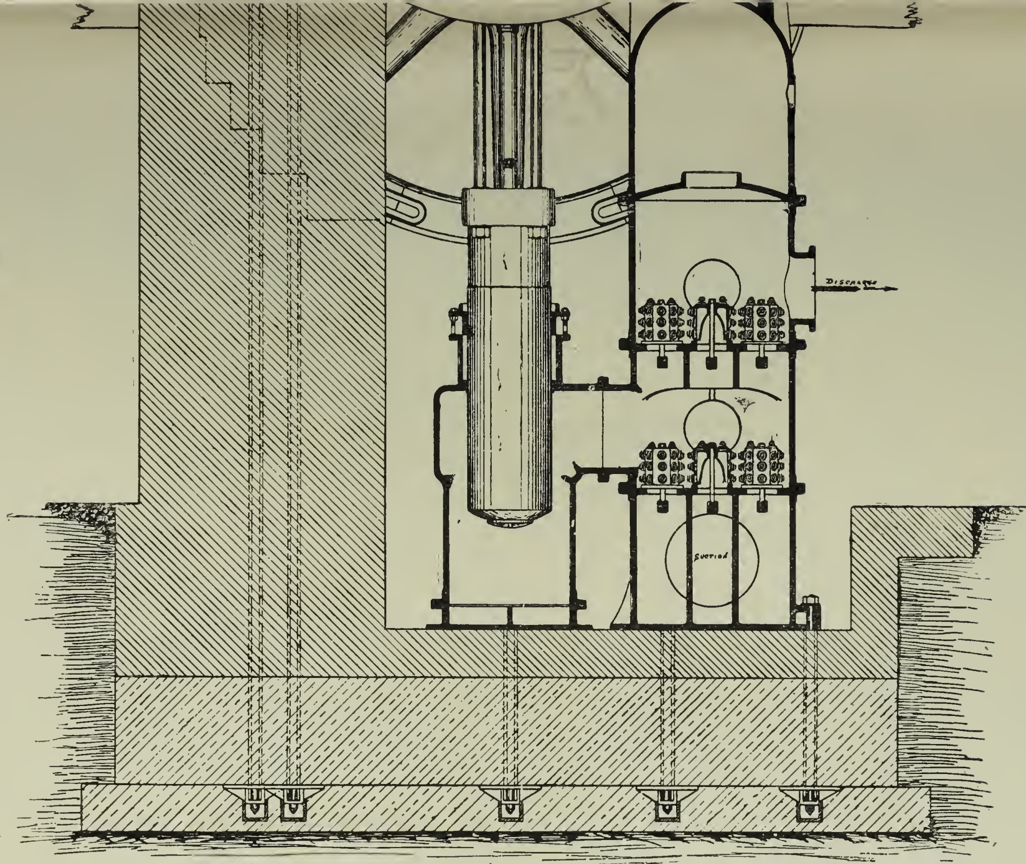


FIG. 4. END ELEVATION OF ENGINE AND SECTION OF PUMP, TRIPLE EXPANSION PUMPING ENGINE. NORTH POINT PUMPING STATION, MILWAUKEE, WIS.

The arrangement of the plant for the test is shown quite clearly in the plan view, Fig. 2. Arrangements were made for measuring the feed water supplied to the boilers and the amount of coal consumed during the time of the test. Indicator diagrams were taken once in fifteen minutes. Temperatures of feed water, discharge jacket water, the external air, engine-room and flue gases were taken and are given in the results. The total consumption of water used during the test is obtained by measurement of the feed water supplied to the boilers. This feed water was obtained from the hot well of another engine, and the condensed steam from this engine was, during the test, discharged into the overflow and wasted. The steam which was used to supply the jacket of the engine was measured by receiving the overflow from the various jacket-traps into weighing tank, No. 3, and returned as a portion of the feed water to the boilers.

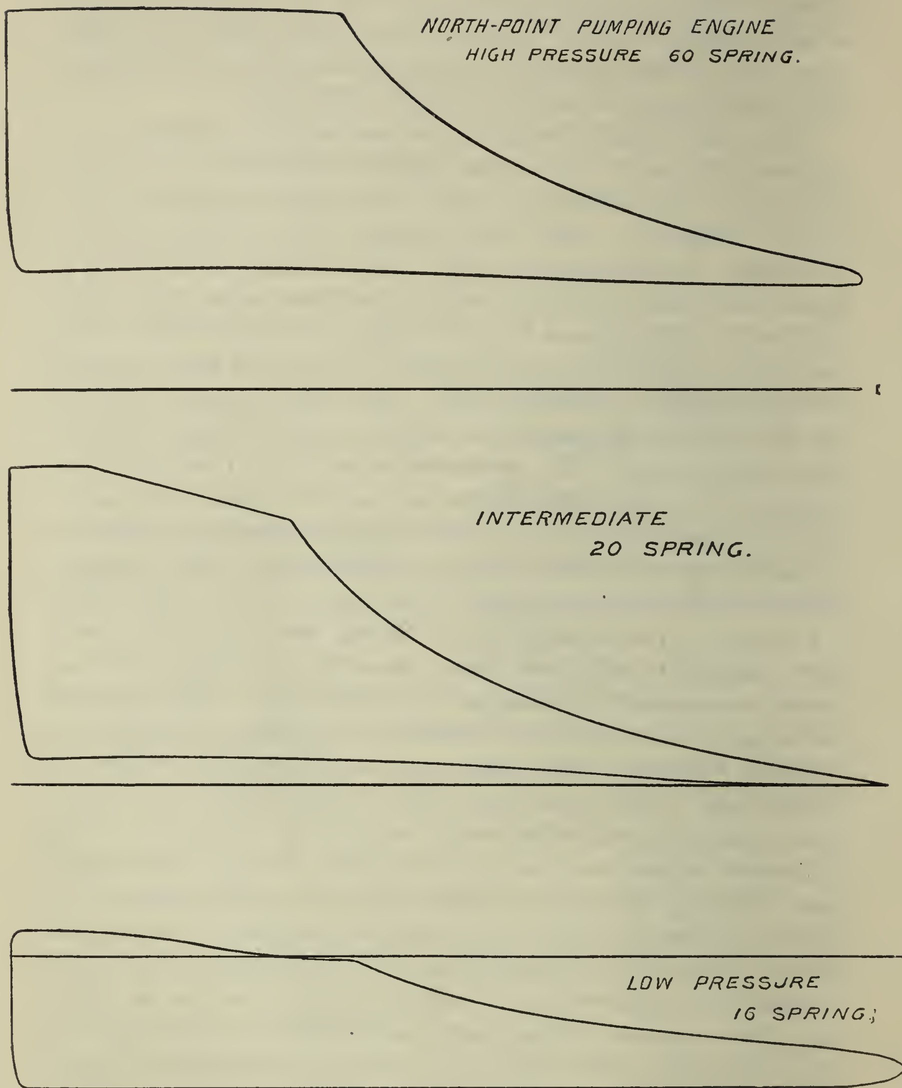
The method of measuring the feed water was to receive it into two barrels, each of which were carefully calibrated by weighing on a pair of scales when filled to a certain fixed overflow. The method of arranging the barrels for this purpose is shown in Fig. 2, from which it is seen that the overflow was a tube extending upward from the bottom to a certain height, the discharge of which was carried off in the waste and did not enter the feed water. The top of this overflow pipe was filled to a sharp edge and was made truly horizontal. From some experiments made with this type of weighing apparatus, the writer has been led to the conclusion that the error in each tank of water need not exceed one-twentieth of one pound, and is ordinarily much less than can be obtained by barrels standing on a pair of scales. During the test the feed water was supplied alternately to two barrels, arranged as explained, and numbered respectively 1 and 2, one barrel being filled while the other was emptying. The emptying was done through a valve, connected to a pipe, leading from the bottom of the barrel and arranged so that any drip could be plainly seen by an observer. The discharge from these feed tanks was led into a tank composed of two barrels connected together and standing on a lower level, to which the feed pump for the boilers was directly connected. The discharge water from the jackets was

received in a barrel similarly arranged and discharging into the same barrels as Nos. 1 and 2. During the test one attendant was supplied to operate the valves on each of the weighing barrels, and, in addition, two observers, one of whom was supplied by the builders of the engine, the other by the party from Cornell University, kept independent logs of the water supplied to the boilers. In each case the time of emptying the measuring tanks was recorded, also the number of the barrel emptied at the time. The measuring barrel for the jacket water, which is designated No. 3 on our log, was supplied with a float for measuring the amount of water instead of the overflow, as described for the other measuring tanks. This barrel was emptied in each case whenever the float reached a certain standard height, the corresponding weight of water for that case being obtained by weighing. With this barrel the percentage of error would be, as compared with the others, relatively large, but as the total number of times that barrel No. 3 was emptied was comparatively small, the effect on the result was correspondingly reduced. The actual error in barrel No. 3 may have reached one-half of one per cent., but as the amount measured in this barrel was less than 8 per cent. of the whole amount used, this error becomes insignificant.

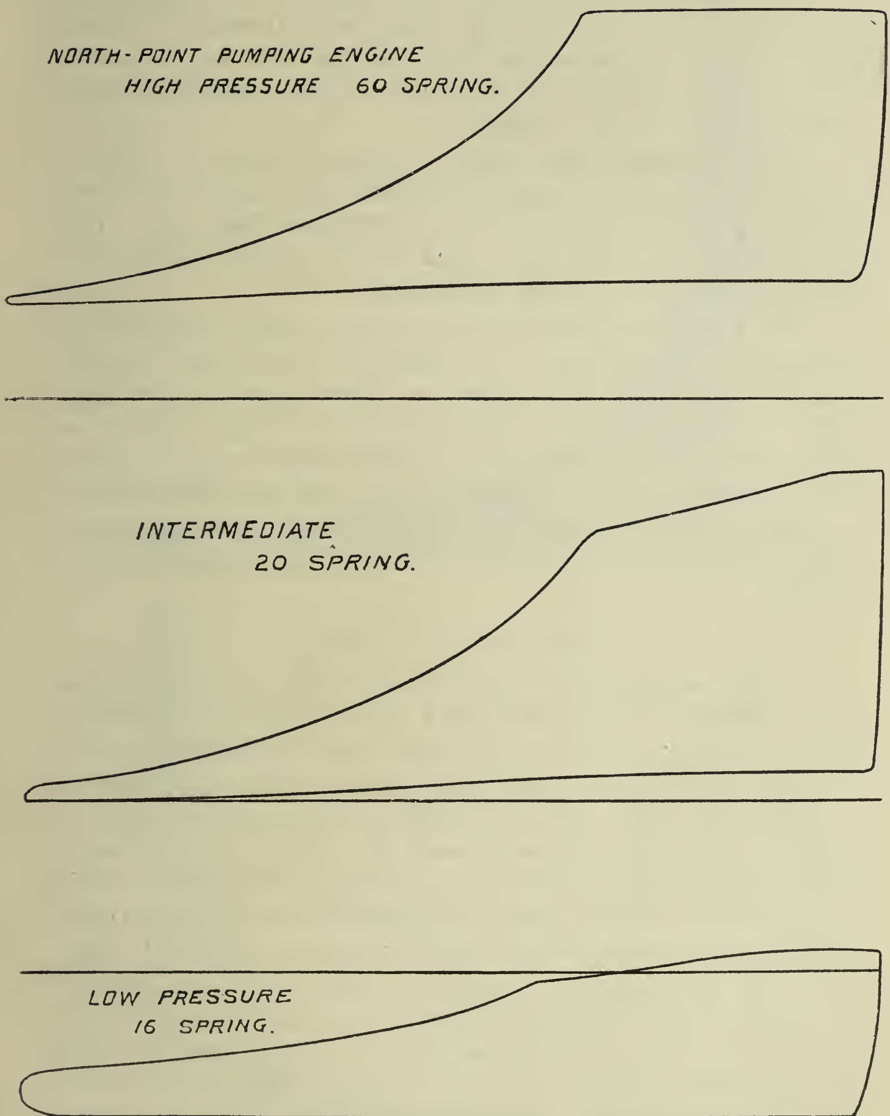
The log gives the total amount of feed water without correction of any sort, but, in obtaining the full amount of water used in the jackets of the engine, a correction was found necessary, which does not in any way affect the total result, but simply the division or percentage which was consumed in the jackets. This correction was necessary for the reason that the discharge of water from the jacket-traps was at a temperature due to the pressure of steam on the jackets. This being in excess of 212 degrees gave considerable loss, due to evaporation. Most of this evaporation was prevented by passing the pipe from the jacket-traps through a large body of cold water and closely covering the top of barrel No. 3, into which this water was received. Still, however, some loss from evaporation occurred, and a careful test was made to determine the amount of this evaporation by allowing the barrels to stand for a given time on a pair of scales when in the same condition as during the test. The results of this test indicated a loss due to evaporation of from 60 pounds as a minimum to 120 pounds as a maximum of steam per hour ; in making up the percentage that jacket water bears to the whole, the maximum correction was used. This is

certainly sufficient to account for the full amount used in the jackets. Had no correction been made for this, the total amount of jacket steam as given by barrel No. 3 would have been about 8 per cent. of the whole, but using the correction, as explained, the jacket water becomes 9.25 per cent. of the total.

The fuel burned during the test was carefully weighed as it was brought into the boiler-room, and the results were checked by two independent observers, one of whom was furnished by the engine builders, the other by our party. The arrangement for measuring the temperature of the flue consisted in inserting a thermometer, the accuracy of which had been tested and which could read to 700 degrees F., in the upper portion of the breeching and also by inserting a pyrometer into the center of the breeching directly beneath the thermometer. The thermometer used was one in which nitrogen gas of low density occupied the space directly above the mercury. The pyrometer was of a kind in which the pressure of a hydro-carbon vapor was used as a means of measuring the temperature. The one used being manufactured by Shaffer & Budenburg and called by them a thalpotasimeter. The readings of the two instruments, as shown by the log of the test, differed but few degrees. The thermometer in the top part of the flue generally reading 2 to 8 degrees higher than the pyrometer, and was much more sensitive to changes in temperature. The quality of the steam was measured by attaching a throttling calorimeter of the kind designed by the writer, and manufactured by Shaffer & Budenburg, to the main steam pipe directly above the boilers. The connection was made very carefully by screwing a long perforated nipple into a vertical portion of the main steam pipe. During the test the steam pressures varied only a few pounds, the water level in the boilers was kept very nearly constant, so that the determinations made with the calorimeters showed, in every instance, a uniform quality of steam, as might have been expected. This quality was 98.95 per cent. throughout the whole test. The boilers were carefully examined for leaks. Some leakage being detected in the blow-off pipes, these were disconnected and their ends plugged several hours before commencing the test. A slight leak of steam was found in one of the joints of the main steam pipe between the boilers and the engine. This leak could not be stopped; it was, however, of small amount and no correction was made for it.



INDICATOR DIAGRAMS BOTTOM END No. 50.



INDICATOR DIAGRAMS TOP END No. 50.

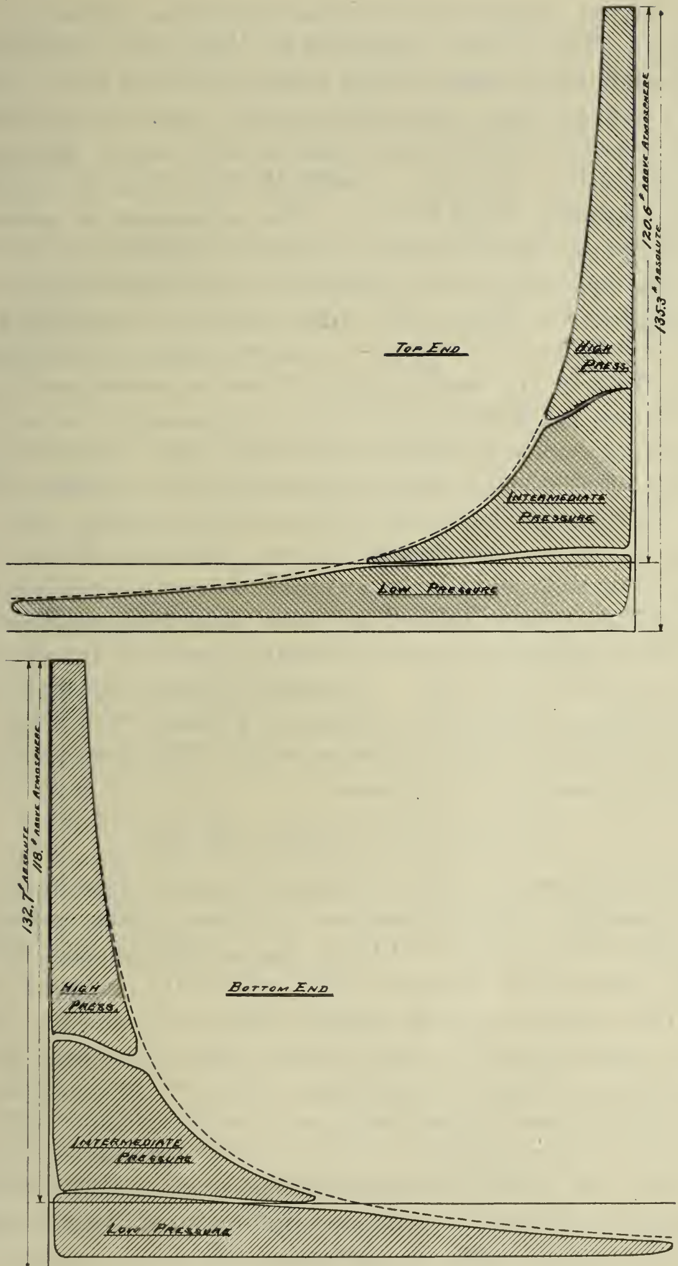
The reducing motions used on the engines were supplied by the makers, and were reducing wheels with threaded or spiral grooves for the cords, so that the diameters were kept constant. The reducing motion was accurate and the diagrams taken were satisactory in every respect.

The draft-gauge was a simple U-shaped manometer, with vernier attachment for reducing small variations in pressure, the form used being that manufactured by the Hartford Boiler Co. This was attached to a small pipe nipple inserted into the side of the breeching at a point near the pyrometer.

The flue gas was obtained from time to time during the test and analyzed immediately. The apparatus used being a portable form of Orsat's apparatus, known as Fisher's gas analysis apparatus. A full description, with method of using, is given on pages 432–6 in Text-book of Experimental Engineering, and need not be described here. A sample of the gas was obtained from a perforated nipple extending into the center of the breeching and was drawn by an aspirator directly into the apparatus for analysis.

CHARACTER OF THE COAL.

The coal burned during the test was from the Pocahontas mine, Virginia. It was a soft, black coal, very uniform in character, and, as shown by the analysis made later by Geer and Garrels at Sibley College, was very high in fixed carbon and possessed very little ash. The coal was slightly damp, and on drying a weighed sample for 48 hours over the boilers a reduction in weight of 5.2 per cent. occurred. By mixing several portions of the coal taken from various parts of the pile together, and selecting a small quantity, a sample was obtained for analysis at Sibley College. This coal was shipped by express in a bag, was several days on the journey and was apparently much drier than the coal used during the test. It, however, showed 3.62 per cent. of moisture after reaching Sibley College. During the test the amount of ash found under the grates and after thoroughly shaking the fire was less than 1 per cent. The analysis which was made at Sibley College showed 1.47 per cent. of ash. The discrepancy probably being due to ash drawn into the chimney by the draft, the total difference re-



COMBINED INDICATOR DIAGRAMS,
North Point Pumping Engine.

quired for this would be a loss equal to less than 80 lbs. for the whole test. The analysis of the coal by Messrs. Geer and Garrels gave the following results: Fixed carbon, 90.87 per cent.; hydrocarbons, 7.66 per cent.; ash, 1.47 per cent. Two trials were made to determine the heating power in a coal calorimeter, giving the following results: Trial No. 1, 14276 B. T. U.; Trial No. 2, 14182 B. T. U., Average, 14232 B. T. U. The evaporation per pound of dry coal was 9.4 pounds under the actual conditions of the test, which was equivalent to an evaporation of 10.72 pounds from and at 212 degrees F. This is not a large evaporation considering the character of the coal. The low evaporation being no doubt largely accounted for by the small amount of coal consumed per square foot of grate per hour. This being 7.15 pounds of actual coal, which is equivalent to 6.76 pounds of dry coal. There was also considerable difference in the results obtained by the different firemen. Fireman "A" was on five hours at the beginning of the test and three hours at the close of the test; Firemen "B" and "C" were each on duty eight hours. A careful accounting of the condition of the fires, coal burned and water evaporated was made for each watch and these show the following results as the evaporation per pound of dry coal: 1st watch, Fireman "A," 9.88; 2nd watch, Fireman "B," 9.23; 3rd watch, Fireman "C," 9.23; 4th watch, Fireman "A," 9.87; average, 9.425. The above values are corrected for moisture in the coal.

APPARATUS USED DURING THE TEST.

The instruments used for obtaining the work done by the engines consisted of four Thompson and two Crosby indicators. The scale of the springs used being, for the high pressure 60 lbs., for the intermediate pressure 20 lbs. and for the low pressure 16 lbs. These springs were all carefully calibrated under the conditions of actual use, and in the indicators which were used during the test, the results of this calibration are given in the appended log, and is also shown graphically on a large scale and with the errors very much magnified. (Fig. 5.) The apparatus employed for testing the indicator springs was that used in Sibley College, it consists essentially of an accurate weighing apparatus or manometer and a steam drum for regulating the steam pressure and means of attaching the indicator so that it shall be under the same pressure as the manometer, while arranged so that diagrams

can be taken. As will be noticed every spring had an error of appreciable magnitude. The errors in some of the springs were negative and in others positive. The resultant effect of the correction being to change the indicated horse power by nearly 1 per cent. The factors for correcting errors in the indicator springs are given in the appended results.

The thermometers used for obtaining temperature measurements were all standard high grade instruments, but in each case were carefully calibrated for boiling point and in every case found essentially correct. The results of the calibration are given in the table of appended results.

The scales on which were weighed the coal burned and the water used, were calibrated by the custodian of the standard weights of the City of Milwaukee and found to read 0.25 of one per cent. too high, and this amount is deducted from all the readings.

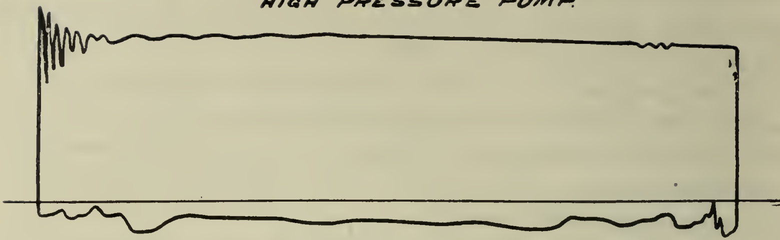
The pressure gauges used on the water column and on the steam pipe and receivers were calibrated by comparison with a Square-inch Gauge, the errors found were in all cases negative, and were deducted from the average readings given in the report. The error in the steam gauge was 4 pounds, that of the water pressure gauge, one foot of water.

The dimensions of the engine and pumps were obtained by G. H. Benzenberg, city engineer of Milwaukee, and his certificate is appended to the report. Before commencing the test, the pumps were carefully examined by Mr. Hamilton, the first engineer of the station, and myself, and found, so far as could be determined by permitting the water pressure to be sustained by the valves and plungers alternately, to be perfectly tight—in fact, no leakage of any kind was to be found.

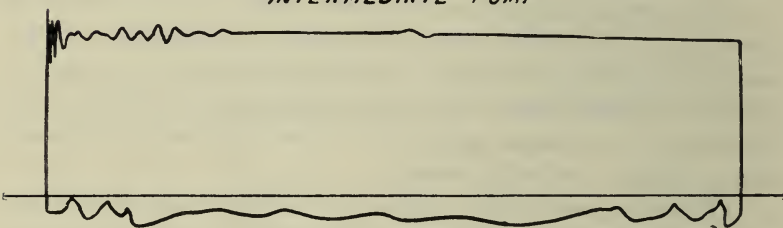
PRELIMINARY TEST.

A preliminary test of several hours in duration was made on March 23d, 1893. In this test it was attempted to discharge the injection water over a weir and thus obtain its amount. The location of the weir is shown in the drawing, Fig. 2. This test, however, did not succeed, as it threw a load on the circulating pump which it had not been designed to carry, and it was found necessary to return the injection water to the suction chamber as in the usual condition of working. Arrangements were made, however, to obtain the jacket water as previously explained.

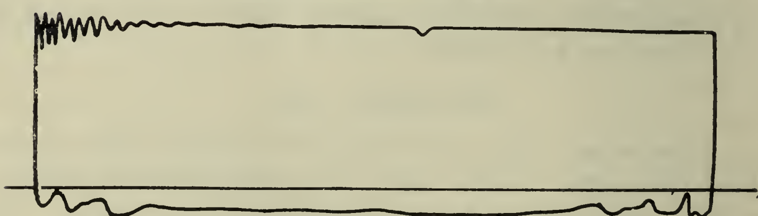
HIGH PRESSURE PUMP.



INTERMEDIATE PUMP



LOW PRESSURE PUMP.



DIAGRAMS FROM PUMPS.

THE PRINCIPAL TEST.

The principal test was commenced at 9 A. M., March 25th, and was continued without interruption for twenty-four hours. The method followed throughout the test was substantially that described in the report to the American Society of Mechanical Engineers on a standard method for testing pumping machines.

At the beginning of the test the condition of the fires were carefully observed in each of the boilers, the height of the coal above the grate bars noted, the water level in each of the boilers was carefully measured and its height marked by a string placed on each gauge glass. These conditions were noted by several observers, both at the beginning and at the end of the test. To prevent any error due to change of water level, the position of these strings on the gauge glasses was observed once in fifteen minutes, and the variation in level of water up or down, noted and recorded. These results are given fully in the appended log. It was not necessary to clean the fires or even to touch them with rake or slice bar during the whole test, and they were cleaned only after the completion of the test. After the final cleaning of the fires, the height of the coal on the grate bars was compared with the original marks and found slightly higher, but not sufficiently so as to require in the judgment of the observers any correction whatever, and none was made. This method is believed by the writer, from an extended experience in boiler trials, to give more accurate results and to involve less error than the method of drawing all the fire at the beginning and end of the test and of starting a fresh fire at the beginning of the test with wood. By carefully watching the time necessary to put in fresh coals in order to prevent a fall in steam pressure, the writer was led to the conclusion that our maximum error would not exceed by this method the amount of coal consumed during five minutes of time, which in this case might be about one-fifth of one per cent. of the total coal consumed. During the test three firemen were employed, who were on at four different watches, as already explained, the same fireman closing and beginning the test. A careful comparison of the work done during each watch by the different firemen was made, and the results are shown in the appended table. A great difference is noted, due to the fact that Fireman "A," who was on during the first and last watches,

habitually kept thinner fires, a higher temperature in his boiler-room, and in general a better management of his fires in a manner that can hardly be described. During the whole test, by order of the chief engineer, Mr. Thomas McMillan, the ash pit doors were fully open, the draft being regulated by operating the damper in the flue connecting the boiler to the breeching. During the test, flue gas analyses were made several times, the results in every case showing a high excess of free air and no CO. The temperature of the flue was also comparatively low, averaging only about 56 degrees higher than that of the steam delivered, this being due, no doubt, to the small consumption of coal per square foot of grate surface per hour. The flue temperature averaged 403 degrees as read by the pyrometer, and 406 as read by the thermometer.

The weight of water delivered by the pumps was computed from the volume of plunger displacement, multiplied by the weight of water at the required temperature, 34 degrees, as obtained from Kopp's tables. The weight per cubic foot taken being 62.42 pounds. The total weight for each revolution of the engine being 5229.2917 pounds. The average head pumped against during the test was 161.84 feet. During the test the head was measured by a pressure gauge connected to the discharge chambers of the pumps; readings were taken once in fifteen minutes. The hand of this gauge remained very steady, there being scarcely any fluctuation, and it could be read accurately at each observation to within one-half foot of the pressure head.

The total head increased slowly during the day, due to a rise in the reservoir into which the water was delivered. The average for the difference in watches of firemen being as follows:

First watch, 9 A. M. until 2 P. M. 161.46
Second watch, 2 P. M. until 10 P. M. 161.644
Third watch, 10 P. M. until 6 A. M. 162.008
Fourth watch, 6 A. M. to 9 A. M. 162.365

THE RESULTS OF THE TEST.

The complete results of the test with the average data is given in the table appended to the report. The principal quantities were as follows: The total indicated horse-power was 573.87, which was divided among the different cylinders; high pressure cylinder 175.39, intermediate cylinder 169.62, low pressure 228.86; the steam pressures were, on the high pressure cylinder 121.46, first

receiver 32.43, second receiver 1.5 ; the total water evaporated into dry steam corrected for the amount used by the calorimeter was 6700.7 pounds per hour, which is equivalent to 11.678 pounds of dry steam per indicated horse-power per hour. The heat supplied to the engine per minute in B. T. U. averaged 124,890.7 which is equivalent to 217.6 per indicated horse-power. The latter number accounts for all heat carried over by the entrained water. The delivered horse-power as computed from the pressures and volume of water delivered by plunger displacement was 520.96. The horse-power required by this computation to overcome the friction of the engine was 52.92 which is 9.22 per cent. of the whole.

The work as obtained from the plunger displacement of the pump was 1,031,520,000 foot pounds of work per hour. The dry coal consumed per hour was 719.8 pounds, thus giving an actual duty per 100 pounds of dry coal consumed equal to 143,506,470 foot pounds. This duty for 1,000 pounds of feed water, or on the supposition that each pound of dry coal actually evaporated 10 pounds of feed water, would have been 152,448,000 foot pounds. This duty, reckoned on the basis of million B. T. U. supplied to the engine, gives as the result 137,056,000 foot pounds.

The gentlemen who took part with me and assisted in conducting the test were as follows: Mr. J. C. McMynn, M. E., Engineer of Tests for Robert W. Hunt & Co., Chicago; Mr. John H. Lewis, Mechanical Engineer for the Edward P. Allis Co.; Mr. Thomas McMillan, Chief Engineer of the Pumping Station of the City of Milwaukee, and Mr. Hamilton, First Engineer of the North Point Pumping Station; and the following gentlemen, all students in Sibley College, Cornell University: R. S. Hale, G. R. Harvey, A. T. Kelsey, M. E.; E. F. Folsom, B. S.; G. C. Purdy, C. J. Toerring, R. H. White, G. P. Witherbee and J. R. Whittemore, M. E.

One of the principal objects of the test was to secure data for the graduating theses of Messrs. Whittemore, Folsom and Harvey; a great deal of the computation in connection with the test has been done by these gentlemen, and I am indebted to them for the results. They have in every case recomputed and checked all results here given, and in addition have worked out the data which were taken in a later test to determine the heat losses as given by the method of testing required for a Hirns' Analysis.

The engine was first started August 23d, 1892, the official test was made under the charge of G. H. Benzenberg and Mr. J. H. Lewis, July 12th to 13th, 1892, for the duty of the pumping engine, and July 20th, 1892, for the economy. The following are the results of those tests:

OFFICIAL TRIAL, TRIPLE EXPANSION PUMPING ENGINE, NORTH POINT STATION, MILWAUKEE, WISCONSIN.

	1892.	
Duty trial	July 12–13	
Economy trial		July 20
Duration, hours	24	24
Total revolutions of engine	29,566	29,524
Revolutions per minute	20.532	20.503
Average steam pressure by gauge	125.8	125.33
Average vacuum pressure by gauge	13.794	13.75
Average first receiver pressure by gauge	28.17	29.83
Average second receiver pressure by gauge	0.406	1.10
Barometer, inches	27.99	
Total head of water pumped against	153.56	
Average temperature of feed water, Fah	130°	132.2°
Total coal burned (Anthracite egg)	18,700	19,200
Total ashes	2,690	3,187
Per cent. of ashes and refuse	14.385	16.6
Actual evaporation per pound of coal	8.76	8.758
Equivalent evaporation from and at 212°	9.91	9.89
Coal per square foot of grate per hour		7.5
Total number of gals. pumped by plunger displacement	18,528,657	
Average indicated horse power	557.029	576.449
Total weight of feed water		168,163
Feed water per I. H. P. per hour		12.155
Coal per I. H. P. per hour		1.387
Duty per 100 pounds of coal burned, ft. pounds	126,865,240	
Duty on supposition that evaporation was 10.27 from and at 212°, ft. pounds	132,950,524	
Duty as above, coal supposed to have 3 per cent. water	136,900,000	

The results of this test compared with the one made March, 1893, show a duty when reduced to the same basis about 1½ per cent. less than that obtained, and a water consumption per indicated horse power about 3 per cent. greater. In the test made by Benzenberg and Lewis, no calorimeter was used and no correction was made for entrained water in the steam. The boilers were not especially examined for leaks, and Mr. Lewis thinks it possible that the leak which was discovered later in the blow-off pipes and stopped, existed at the time of making their test. These corrections probably account for nearly the entire amount of difference shown by the two trials.

A subsequent test made by the E. P. Allis Co., April 7, to determine the heat used by the condenser, gave the following results:

Average revolutions per minute	20.41
Average steam pressure by gauge	121.6
First receiver pressure	31.9
Second receiver pressure	1.67
Vacuum below atmosphere	13.5
Temperature of injection water	40°
Temperature of discharge water	98°
Depth over weir, 12-inch notch, feet	0.2669
Cubic feet per minute	26.78
Pounds of injection water per minute	1660.0
Pounds of feed water per minute	111.6
Ratio injection water to feed water	14.9
Per cent. of heat carried off in jacket water	9.25
" " " " exhaust	75.10
" " " " discharge water	15.65
Probable quality of steam in exhaust from the low press. engine	84.3

As a check on this result a computation of the quality of steam obtained in the various cylinders on the test of March 24 and 25 was made by comparing the actual water consumption with that shown by the indicator diagrams. The quality of steam, as shown by this computation, was a follows:

High pressure cylinder, at cut off	89	per cent.
" " " release	93	"
Intermediate, at cut off	86.0	"
" release	97.5	"
Low pressure, at cut off	77.8	"
" " release	85.6	"

DIMENSIONS OF BOILERS.

North Point Pumping Station, Milwaukee, Wis. Steam was supplied by four plain tubular boilers constructed by The E. P. Allis Co., each having the following dimensions:

Length	18 feet.
Diameter	66 in.
Grate	5 ft. long, 5 ft. 4 in. wide.
Grate surface	26.65 sq. ft.
Tubes in each boiler, 55	diameter, 4 in.
Area of tubes in each boiler	4.68 sq. ft.
Water heating surface	1,216 sq. ft.
Ratio of heating to grate surface	35
Height of chimney	125 ft.
Area of chimney	12.566 sq. ft.
Total grate surface of the 4 boilers	106.6 sq. ft.
Total heating surface	4864.0 sq. ft.
Bottom of gauge glass to bottom of boiler shell	3′ 1½″

BOILER TEST.

Duration of test	24 hrs.
Barometer, inches of mercury	29.54
Atmospheric pressure, pounds per sq. in	14.5
Steam gauge corrected (at engine)	121.6
Draught gauge, inches of water	0.4025
Absolute steam pressure	136.1 lbs.
External air, temperature deg. F	25.71
Boiler-room, " "	50.
Flue { Thermometer in top, deg. F	406.02
Flue { Pyrometer in center, "	403.02
Feed water, deg. F	97
Steam, deg. F	350.6

FUEL.

Total coal consumed, pounds	18,234
Moisture in coal per cent	5.25
Dry coal consumed	17,277
Total ash, dry, pounds	255
Total ash, dry, per cent. of dry coal	1.47
Moisture and ash, per cent. of wet coal	6.65
Total combustible, pounds	17,022

FUEL PER HOUR, POUNDS.

Actual	759.75
Dry coal	719.84
Combustible	709.25
Actual coal per sq. ft. of grate	7.15
Dry coal " " "	6.76
Combustible" " "	6.65

CALORIMETER.

Temperature of steam in calorimeter, deg. F	284.6
Back pressure in calorimeter, inches of mercury	1.9
Quality of steam	98.95
Per cent. of entrained water	1.05
Number of minutes calorimeter was open	114
Steam used in calorimeter, pounds	208.5

FEED WATER.

Total weight of water used, pounds	162,864
Excess of water in boiler at end of run, pounds	131
Total evaporated into dry steam, pounds	161023.2
Factor of evaporation. (Equivalent value of 1 lb. wet steam to 1 lb. dry steam from and at 212 F.)	1.154
Total equivalent evaporation from and at 212 deg. F., pounds	187,794

FEED WATER PER HOUR, POUNDS.

Actual amount used, pounds	6780.5
Evaporated into dry steam	6709.4
Equivalent, evaporated from and at 212 deg	7710

EVAPORATION PER POUND OF COAL, POUNDS.

(*a*) Apparent, feed water 97 deg. steam 121.4	8.906
(*b*) Actual to dry steam	8.81
Equivalent from and at 212 deg	10.27

EVAPORATION PER POUND OF DRY COAL, POUNDS.

(*a*) Apparent, feed water 97 deg. steam 121.4	9.425
Equivalent from and at 212 deg	10.72

EVAPORATION PER POUND OF COMBUSTIBLE, POUNDS.

(*a*) Apparent, feed water 97 deg. steam 121.4	9.56
Equivalent from and at 212 deg	10.88

(*a*) Uncorrected for calorimeter. (*b*) Corrected for calorimeter.

EVAPORATION PER HOUR.—PER SQUARE FOOT OF GRATE.

Actual, uncorrected for moisture, pounds	63.6
Equivalent from and at 212 deg., pounds	73.2

PER SQUARE FOOT OF WATER HEATING SURFACE.

Actual, uncorrected for moisture, pounds	1.505
Equivalent from and at 212 deg., pounds	1.73

PER SQUARE FOOT OF LEAST DRAFT AREA.

Actual, uncorrected for moisture, pounds	373
Equivalent from and at 212 deg. pounds	429

HORSE POWER.

On basis 30 lbs. from 100 deg. F. to 70 lbs. pressure	223.5
Builder's rating	400
Ratio of boiler H. P. to capacity, per cent	55.7

EFFICIENCY OF BOILER.

(A) Heat generating per hour on basis of 14500 B. T. U. each lb. of combustible	10,285,125
(B) Heat absorbed by steam per hour, B. T. U	7,554,833
Efficiency of boiler, (A) ÷ (B), per cent	73.45

TRIPLE EXPANSION PUMPING ENGINE.

DIMENSIONS.

Length of stroke of each piston	60 inches
Diameter of high pressure cylinder	28 "
Diameter of intermediate pressure cylinder	48 "
Diameter of low pressure cylinder	74 "
Diameter of piston rod in each cylinder	4 "
Number of piston rods in all cylinders	6
Clearance high pressure cylinder, per cent	1.4
" intermediate pressure cylinder, per cent	1.5
" low pressure cylinder, per cent	0.77
Volume of first receiver	101.3 cu. ft
" second receiver	181 cu. ft
No. of reheater pipes, first receiver	57
" " " second receiver	35
Diameter reheater pipes	2 inches
Number of single acting water plungers	3
Diameter of each	32 inches
Diameter of single acting air pump	20 "
Diameter of single acting plunger feed pump	$2\frac{1}{4}$ "
Diameter of single acting air compressing pump	$2\frac{1}{4}$ "
Diameter of double acting circulating pump	$7\frac{1}{2}$ "
Stroke of all pump plungers	60 "
Distance from center of pressure gauge to center of pump chamber	19.8 ft.
Distance from bottom of well to center of pump chamber	20 ft.

Area of piston, square inches.

	Top.	Bottom.
Area of piston, high pressure	615.745	590.621
" " intermediate pressure	1809.562	1784.429
" " low pressure	4300.85	4275.72

Area of each plump plunger	804.2496 sq. in.	5.585 sq. ft.
Total volume delivered per revolution by one plunger		27.9253 cu. ft.
" " " " " three "		626.688 gals.
" weight " " " " "		5229.291 lbs.

ENGINE TEST.—RESULTS AND DATA.

Duration of test	24 hrs.

AVERAGE TEMPERATURES—DEG. F.

Water at pump well	34.
Feed water to boiler	97.*
Discharge from air pump	105.4
Calorimeter (1.9 inches back pressure)	284.5
Engine-room	69.9
External air	25.71

* This low temperature was due to arrangements for test, normal temperature under working conditions 132°.

AVERAGE PRESSURES.

Barometer, inches	29.54
" pounds	14.5
Gauge at throttle	121.45
Absolute pressure at engine	135.94
Vacuum gauge, pounds	13.84
First receiver gauge, pounds	32.43
Second receiver gauge, pounds	1.3
High pressure jacket, pounds	121.40
Low pressure jacket, by gauge, pounds	34.0
Suction head by float, feet	10.77
Water pressure by gauge, pounds	56.473

REVOLUTIONS.

Total number	29,252
Per hour	1218.8
Per minute	20.314
Quality of steam, per cent	98.95
Moisture in steam, per cent	1.05

FEED WATER AND DRY STEAM.

Total feed water to boilers, pounds	162,864
Excess in boilers at end of run, pounds	131
Steam used by calorimeter (114 min.) pounds	208.5
Total wet steam to engine	162524.5
" dry " "	160818.1
Wet steam to engine per hour	6771.8
Dry steam to engine per hour	6700.7
Heat in one lb. wet steam above 105.4 F. B. T. U	1106.26
Heat supplied engine per hour, B. T. U	7,493,444
Heat supplied engine per minute, B. T. U	124890.7
Total wet steam used in jackets	15,054
Wet steam used in jackets per hour	627.3
Per cent. of total steam used by jackets	9.25

FACTORS FOR CORRECTION OF INDICATOR SPRINGS.

	Top.	Bottom.
High pressure	93.7	97.8
Intermediate	1.036	1.029
Low	98.28	104.91

INDICATED HORSE POWER.

		Uncor'cted.	Cor.
High pressure cylinder	Top	89.698	87.54
	Bottom	89.802	87.85
		178.498	175.39
Intermediate	Top	85.75	88.84
	Bottom	78.5	80.78
		164.25	169.62
Low	Top	118.66	116.23
	Bottom	107.36	112.63
		226.02	228.86
Total		568.668	573.87

Delivered horse power	520.96
Friction horse power	52.91
Friction horse power, per cent	9.22
Feed water per I. H. P., per hour, pounds	**11.8**
Dry steam per I. H. P., per hour, pounds	**11.678***
B. T. U. per I. H. P. per minute	**217.6**

* Best on record.

MEASUREMENTS FROM INDICATOR DIAGRAM.—HIGH PRESSURE ENGINE.

	Top.	Bottom.
Scale of spring	60	60
Abs. Admission pressure	135.3	132.7
Abs. cut off pressure	134.2	132.4
Abs. release pressure	45.0	48.7
Average M. E. P	46.2	48.28
Average I. H. P	87.54	87.85
Cut off per cent. of stroke	35.526	39.264

INTERMEDIATE PRESSURE ENGINE.

Scale of spring	20	20
Abs. admission pressure	50.1	48.1
Abs. cut off pressure	41.5	41.5
Abs. release pressure	15.3	14.34
Abs. compression pressure	16.9	17.1
Average M. E. P	15.97	14.71
Average I. H. P	88.84	80.78
Cut off per cent. of stroke	34.62	32.31

LOW PRESSURE ENGINE.

Scale of spring	16	16
Abs. admission pressure	16.16	16.48
Abs. cut off pressure	13.28	13.92
Abs. release pressure	5.35	5.3
Abs. compression pressure	1.76	1.5
Average M. E. P	8.81	8.58
Average I. H. P	116.23	112.63
Cut off per cent. of stroke	39.59	38.56

RELATIVE VOLUMES OF CYLINDERS.

High pressure	1	1
Intermediate	2.95	3.01
Low	6.95	7.01
Total number of expansions	19.55	

WATER PER I. H. P. PER HOUR FROM DIAGRAMS.

Computed on supposition that all work is done in one cylinder.

		Top.	Bottom.	Av.
High pressure cylinder	cut off	9.87	9.80	9.83
	release	10.24	10.67	10.45
Intermediate	cut off	9.27	8.92	9.09
	release	10.28	10.12	10.2
Low	cut off	8.42	8.41	8.415
	release	9.25	9.22	9.235

PUMP TEST.

Duration	24 hrs.
Temperature of water pumped, deg. F	34
Weight per cubic foot	62.42
Lbs. of water lifted per revolution	5229.2917
Water pressure in pounds	56.473
Delivery head in feet	131.275
Distance delivery gauge to center of pump, feet	19.8
Suction head in feet	10.77
Total head in feet	161.845
Revolutions per hour	1218.8
Foot pounds of work per hour	1,031,520,000
Kilogramme meters per hour	142,556,000
Wet coal per hour, pounds	759.75
Dry coal per hour, pounds	719.8
Kilogrammes of coal per hour	332.23
Combustible per hour, pounds	709.25

DUTY.

Foot pounds of work for 100 lbs. dry coal	**143,306,470**
" " " " " wet "	**135,770,000**
" " " " " combustible	**145,438,000**
" " " 1,000 lbs. of feed water	**152,448,000***
" " " 1,000 lbs. dry steam	**154,048,704**
" " " 1 million B. T. U	**137,656,000**
" " " 1 cwt. coal (112 lbs.)	**152,630,000**
Kilogram meters of work per kilo of coal	**429,110**

* Highest on record.

CAPACITY.

Cubic feet per revolution 3 x 27.9253	83.7759
Gallons per revolution	626.688
Cubic feet per hour	102,122.5
Gallons per hour	763,807
Cubic feet for 24 hours	2,450,940
Gallons for 24 hours	18,331,364

PRINCIPAL QUANTITIES OF BOILER AND PUMP TEST FOR EACH WATCH OF FIREMAN.

Number of Watch.	A.	B.	C.	A.	Total or Avergs.
Duration of hours	5	8	8	3	24
Coal fired	3591	6284	6284	2075	18234
Coal per hour fired	718	785.5	785.5	691.60	759.75
Estimated excess in furnace	—35	110	150	45	....
Coal per hour burned	725	775	776	730	....
Dry coal (cor. for 5.25 per ct.)	688	735	736	693	719.8
Temperature feed water	....	....	....	....	....
Steam pressure at engine	121.43	122.14	121.29	120.41	121.46
Barometer, inches	29.55	29.53	29.52	29.577	29.537
No. bbls. water per watch:					
Bbl. No. 1 net wt. 400$\frac{1}{4}$	45	60	63	24(−20lb)	192−20lb
Bbl. No. 2 net wt. 386$\frac{3}{4}$	45	60	62	24	191
Bbl. No. 3 net wt. 173$\frac{1}{2}$	13$\frac{1}{6}$	24	23	10	70$\frac{1}{6}$
Wt. of water, Bbl. No. 1	18011	24016	25216	9586	....
Bbl. No. 2	17016	23595	23978	9282	....
Bbl. No. 3	2874	4164	3591	1735	....
Total feed water	37301	51775	53185	20603	162864
Excess in tank, end watch	785	750	300	....	....
Excess in boilers (change in ht. on gauge glass, in.)	1.75	0.16	—0.215	0.08	....
Excess in boilers, lbs	2667	259	—365	131	131
Total evaporated during watch	33849	54218	54357	20517	54354
Evaporated per hour	6770	6777	6795	6805	6780.5
Evap. per lb. of coal, actual	9.36	8.74	8.74	9.35	8.906
Calorimeter open, minutes	45	44	....	25	114
Steam used by cal., lbs	82	81	....	45.5	208.5
Quality of steam per cent	98.95	98.95	98.95	98.95	98.95
Temp. of water pumped	34	34	34	34	34
Water pressure in lbs	56.775	56.86	56.96	57.08	56.903
Deliv. hd. in ft. (2.307 ft.=1 lb.)	130.96	131.25	131.31	131.56	131.275
Distance center pump to gauge	19.8	19.8	19.8	19.8	19.8
Suction head in feet	10.7	10.594	10.398	11.005	10.77
Total head in feet	161.46	161.644	162.008	162.365	161.845
Millions of ft. lbs. per hour	1025.008	1032.6	1032.723	1034.995	1031.520
Actual duty from 100 lbs. dry coal burned, millions ft. lbs	150.06	140.08	140.02	150.07	143.30647
Actual duty from 100 lbs. coal burned, millions foot lbs	142.7106	133.238	133.0827	142.7	135.77
Duty from 1,000 lbs. of steam, millions ft. lbs	152.45	152.4	152.3	152.5	152.448

NOTE.

Fireman "A" was on five hours at beginning and three hours at end of test. "B" and "C" each eight hours. "A" carried thin fires; "B" and "C" thick fires. The condition of fires at end of each watch was estimated as follows, compared with conditions at starting:

First watch, (—35 lbs.); second watch, 110 lbs.; third watch, 150 lbs.; fourth watch, 45 lbs.

These results do not have a probable error exceeding one-half of one per cent. The last column gives the total average for the whole run, from which no corrections for excess of fuel are deducted. During the entire test draught was regulated by upper damper.

Water level in boilers observed each fifteen minutes and reported in log. At end of test water level stood with reference to point of starting as follows: In boiler No. 1, 0.23 inches high; in boiler No. 2, exact; in boiler No. 3, 0.19 inches high; in boiler No. 4, exact. Total correction 131 pounds, which was deducted from the total feed water to give the total water evaporated. This correction is about $\frac{1}{8}$ of one per cent. of the total water used.

LOG OF COAL BURNED.

Time.	Lbs. Coal.	Time.	Lbs. Coal.	Time.	Lbs. Coal.	Time.	Lbs. Coal.
A. M.		P. M.		P. M.		P. M.	
9:00	1800	2:06	300	9:52	300	10:25	300
9:05	600	2:09	*300	9:54	300	A. M.	
11:11	300	5:25	300	9:57	300	3:30	300
11:15	300	5:28	300	10:00	300	3:34	300
11:17	300	5:30	300	10:02	300	3:37	300
11:20	*300	5:32	300	10:04	300	3:39	300
P. M.							
1:40	300	5:35	300	10:06	300	4:52	*300
1:43	300	6:00	300	10:09	300	5:56	300
1:46	300	6:06	300	10:11	300	5:59	300
1:49	300	6:11	300	10:13	300	6:01	300
1:52	300	6:14	300	10:15	300	6:05	300
1:55	300	8:56	300	10:17	300	6:09	300
2:00	300	9:00	*300	10:19	300	6:12	300
2:03	300	9:49	300	10:22	300	6:15	300

* Checked total coal burned to this time.

REMARKS.

Test made with bituminous coal, Pocahontas Mine, Virginia. Cleaned fires at end of run only. Tare of barrow 105 lbs.; weighed back 20 lbs. at end of test.

TEST FOR MOISTURE BY DRYING 100 LBS. OF COAL FOR 48 HOURS IN TRAY WEIGHING $36\frac{1}{2}$ LBS.

Original weight	$136\frac{1}{2}$ lbs.
Final weight	131 "
Loss	$5\frac{1}{2}$ lbs.
Scale correction ($-\frac{1}{4}$ lb.), moisture	5.25 per cent.

COAL CONSUMED, SUMMARY.

A, 9 to 2, 5 hours	3,600 lbs.	720 lbs. per hour
B, 2 to 10, 8 "	6,300 "	787 " "
C, 10 to 6, 8 "	6,300 "	787 " "
A, 6 to 9, 3 "	2,100 "	700 " "
Average		761 " "

Total coal	18,280
Ash and clinker	166
Combustible	18,114

COAL DRAWN AS BELOW.		COAL BURNED AS BELOW.	
From	9:00 A. M. to 11:20 A. M.	From	9:00 A. M. to 2:00 P. M.
"	1:40 P. M. to 2:09 P. M.	"	2:00 P. M. to 6:00 P. M.
"	5:25 P. M. to 9:00 P. M.	"	6:00 P. M. to 10:00 P. M.
"	9:49 P. M. to 4:52 A. M.	"	10:00 P. M. to 6:00 A. M.
"	5:56 A. M. to 6:15 A. M.	"	6:00 A. M. to 9:00 A. M.

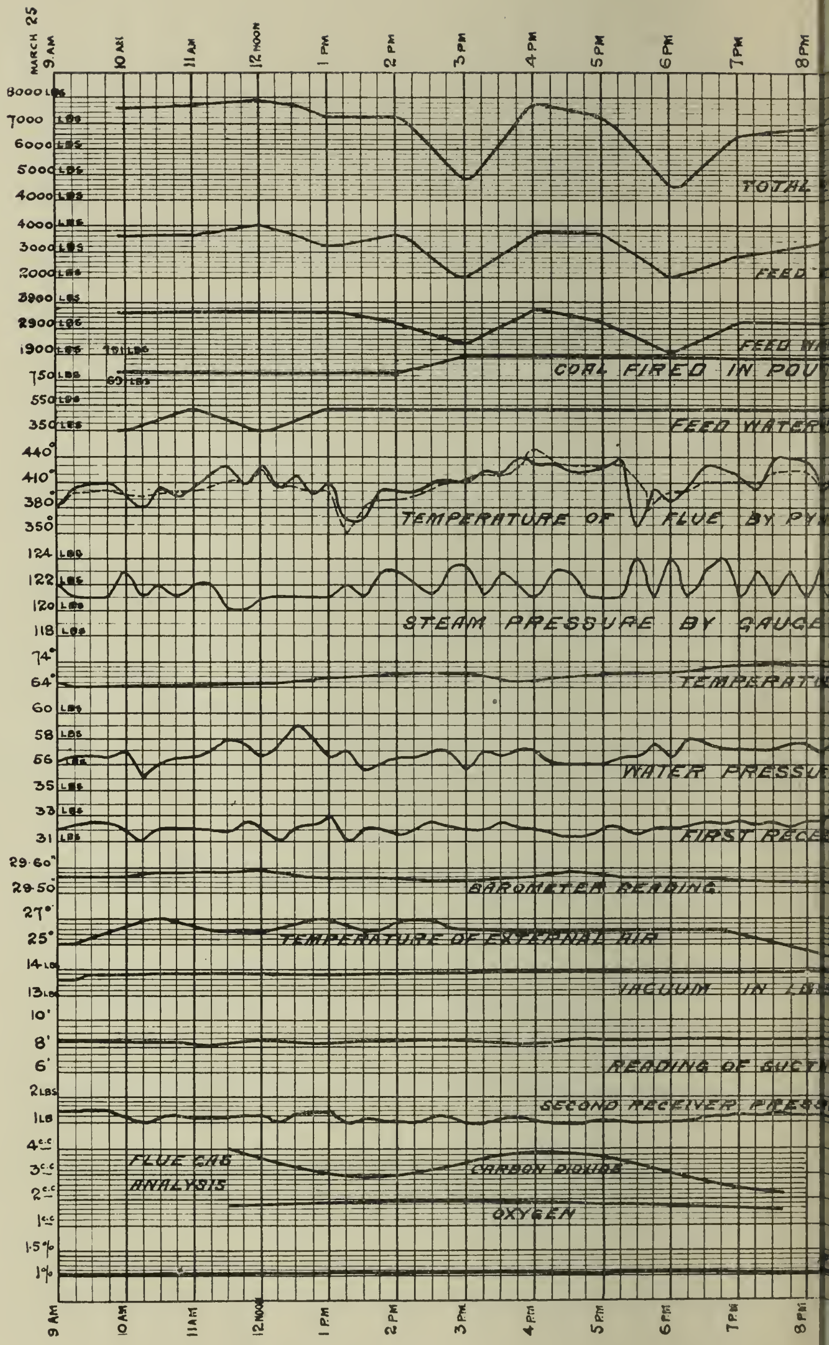
Scale, on being tested with standard weights, reads $\frac{3}{4}$ of a pound too much for each 300 pounds.

ANALYSIS OF SAMPLE COAL TAKEN TO SIBLEY COLLEGE.

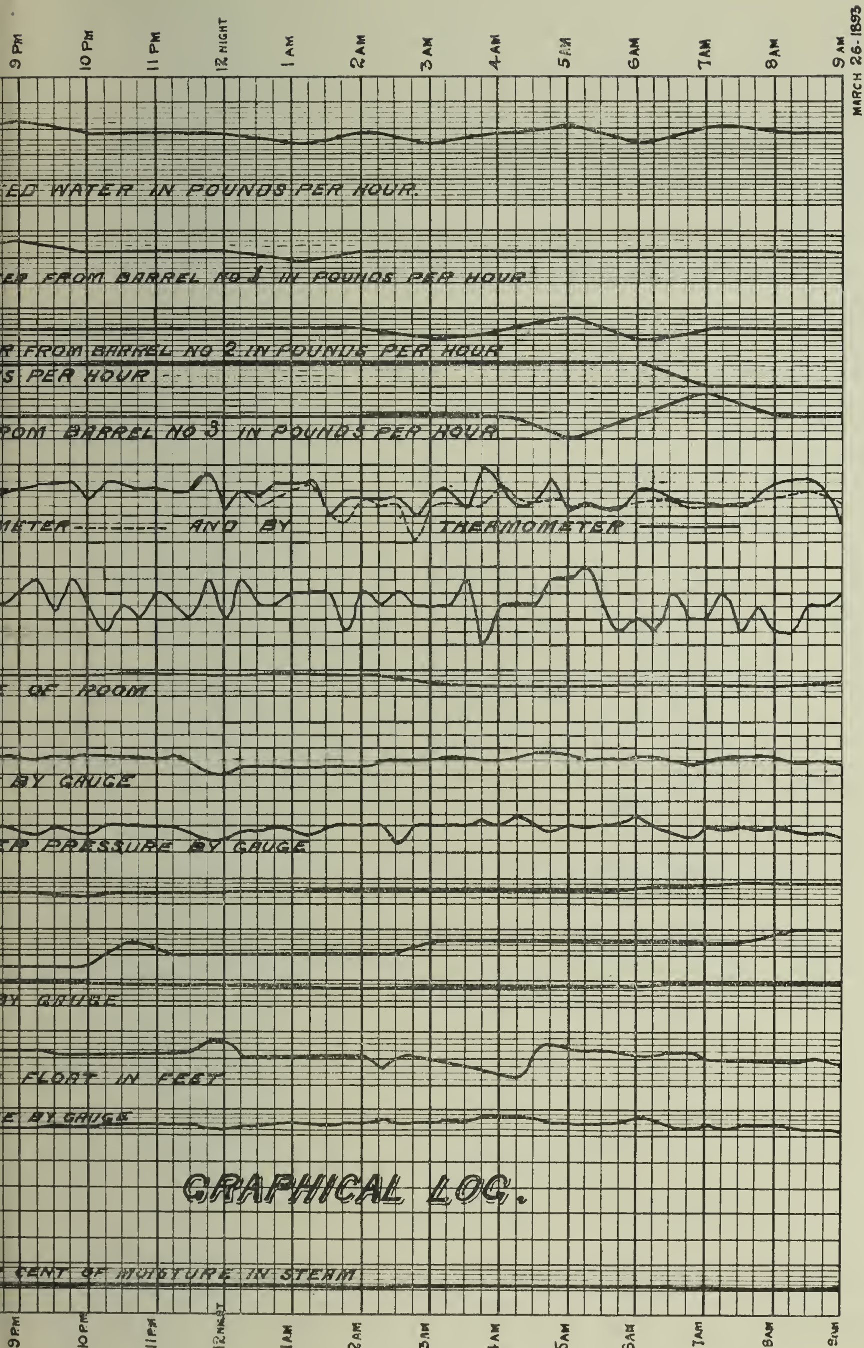
	Per Cent.
Water	3.62
Dry coal contains H	7.66
Fixed carbon	90.87
Ash	1.47
	100.00

B. T. U. IN COAL BY THOMPSON'S CALORIMETER.

First trial	14,276
Second trial	14,188
Average	14,232



MARCH 25
9 AM
10 AM
11 AM
12 NOON
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
8 PM
TOTAL
FEED
COAL FIRED IN
FEED WATER
TEMPERATURE OF FLUE BY
STEAM PRESSURE BY
WATER
FIRST
BAROMETER READING
TEMPERATURE OF EXTERNAL AIR
VACUUM IN
READING OF
SECOND RECEIVER
FLUE GAS ANALYSIS
CARBON DIOXIDE
OXYGEN

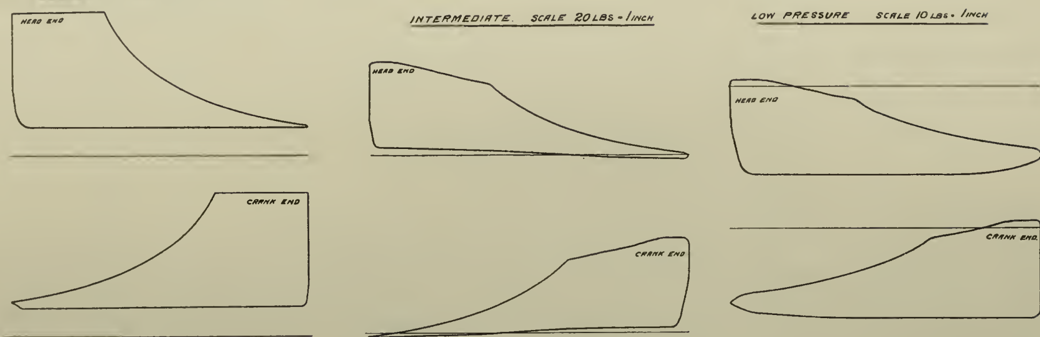


9 PM
10 PM
11 PM
12 NIGHT
1 AM
2 AM
3 AM
4 AM
5 AM
6 AM
7 AM
8 AM
9 AM
MARCH 26-1893
ED WATER IN POUNDS PER HOUR.
ER FROM BARREL NO 1 IN POUNDS PER HOUR
R FROM BARREL NO 2 IN POUNDS PER HOUR
S PER HOUR
ROM BARREL NO 3 IN POUNDS PER HOUR
METER AND BY THERMOMETER
OF ROOM
BY GAUGE
ER PRESSURE BY GAUGE
BY GAUGE
FLOAT IN FEET
E BY GAUGE
GRAPHICAL LOG.
CENT OF MOISTURE IN STEAM

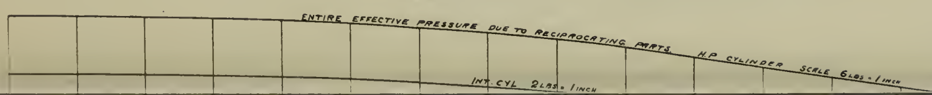
FIG. 5.

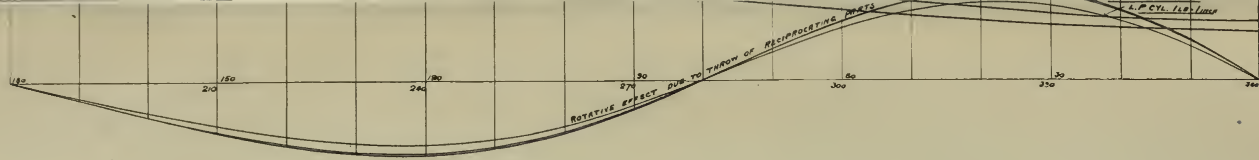
A STUDY OF THE ACTION OF THE RECIPROCATING PARTS OF ALLIS TRIPLE EXPANSION PUMPING ENGINE.

INDICATOR DIAGRAMS TAKEN FROM ENGINE. CYLS 28", 48" + 74" x 60" STROKE.



CURVES SHOWING EFFECT OF RECIPROCATING PARTS.





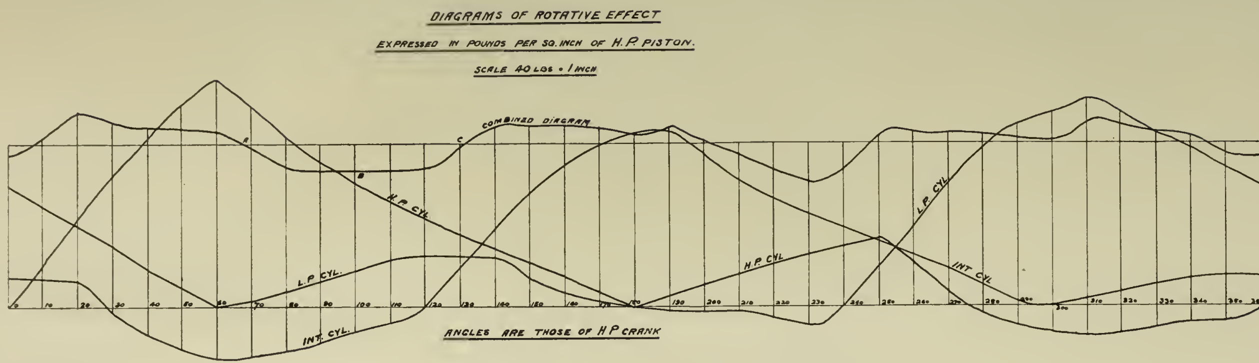


DIAGRAM OF ROTATIVE EFFECT

Allis Triple Expansion Pumping Engine, North Point Pumping Station.

BY PROF. C. H. PEABODY, BOSTON, MASS.

OFFICIAL TEST

OF

THREE

Triple Expansion Pumping Engines

AT

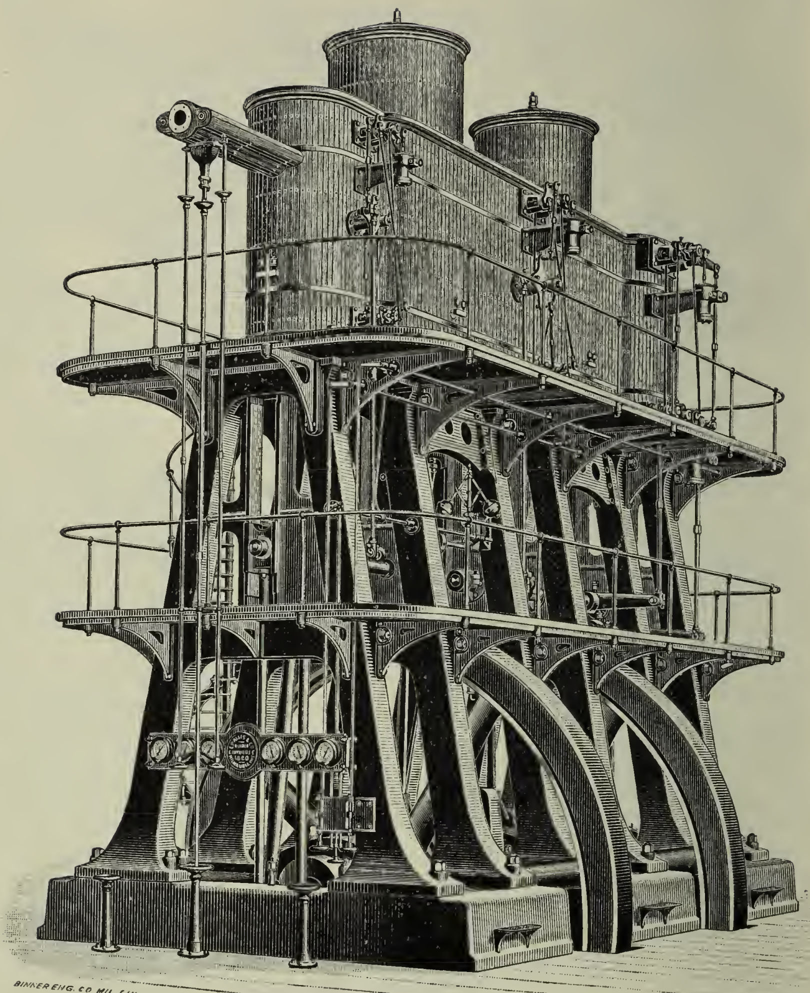
FOURTEENTH ST. PUMPING STATION,

CHICAGO, ILL.

COPY OF EXPERTS' REPORT,

JAMES N. WARRINGTON,
ROBT. W. HUNT & CO.

INTERIOR OF FOURTEENTH STREET PUMPING STATION, CHICAGO, ILL.



ALLIS TRIPLE EXPANSION PUMPING ENGINES.
CHICAGO, ILL.

CHICAGO, ILL., July 5th, 1893.

Mr. Samuel G. Artingstall, City Engineer:

SIR—The undersigned beg leave to submit their final Report of the Duty and Capacity Trial of the Pumping Engines at the Fourteenth Street Station.

The purpose of the trial was to determine the duty and capacity of three pumping engines built by the Edward P. Allis Company of Milwaukee, Wis.

The contract requires that the engines shall develop a duty of one hundred and twenty-five million (125,000,000) foot pounds for each one thousand (1,000) pounds of feed water evaporated, while pumping at the rate of fifteen million (15,000,000) United States gallons in twenty-four (24) hours for each engine, against a head of one hundred and twenty-five (125) feet, at a piston speed of one hundred and sixty-two (162) feet per minute, and with a steam pressure of one hundred and twenty (120) pounds per square inch.

As originally drawn, the contract required the duty to be based on each one hundred (100) pounds of the best quality of Lehigh (Anthracite) coal burned; but the city, for its own benefit, had altered the grates and furnaces prior to the trial, adapting them to the use of inferior grades of coal, at the same time agreeing with the builders that the duty should be based upon the feed water as above stated.

DESCRIPTION OF THE ENGINES.

The engines are three in number, alike in all respects, and are designated No. 1, No. 2 and No. 3. In type they are triple-expansion, direct-acting, crank and fly-wheel, vertical engines with

plunger pumps. Each engine has three steam cylinders in which the pistons are double acting, and three water plungers, which are single acting; all being on vertical axes. The steam cylinders are placed side by side on "A" frames vertically over the pumps and each piston is connected rigidly to its corresponding plunger. The reciprocating parts are of such weight as to equalize the work of the upward with that of the downward stroke, thus enabling the double-acting piston to drive the single-acting plunger without especial assistance from the fly-wheels. Between the steam cylinders and the pumps is the crankshaft, carrying two fly-wheels. The cranks are set 120° apart and each is connected by a rod of usual form to its corresponding cross-head, which works in guides in the cast-iron frame. Each piston is connected to its crosshead by two piston rods, while the connection of the cross-head to the plunger below is by four rods, which avoid the shaft. The pumps are placed in a dry well, so low that the water flows to them. The suction pipes branch from one suction main which connects with the tunnel well outside the building. The pumps discharge directly into the street mains without a stand pipe. The plungers are packed outside with hemp.

All the steam and exhaust valves are of the Corliss type and are placed in the cylinder heads. The cut-off of the high pressure cylinder is controlled by a governor, while the cut-offs of the intermediate and of the lower pressure cylinders are adjustable by hand. The cylinders are all steam jacketed and the receivers have heaters. The jackets of the high pressure cylinder and the intermediate cylinder, and the heater of the first receiver are supplied with steam direct from the boilers; while the heater of the second receiver and the jacket of the low pressure cylinder are supplied with steam at a reduced pressure—about 45 pounds by gauge.

The condensation of the jackets and heaters is discharged through traps and led directly to the suction pipe of the feed pump. The feed pump, air pump and a small pump for supplying air to the air chambers, are all driven by an arm on the low pressure plunger. The principal dimensions of the engines are as follows:

Number of engines		
Number of steam cylinders to each engine		3
Diameter of high pressure cylinder in inches		27
Diameter of intermediate cylinder in inches		46
Diameter of low pressure cylinder in inches		70
Stroke of all pistons and plungers in inches		60
Number of plungers to each engine		3
Diameter of plungers in inches	Engine No. 1 H. P.	32.746
	Engine No. 1 I. P. and L. P.	32.766
	Engines No. 2 and No. 3	32.766
Number of piston rods to each piston		2
Diameter of all piston rods in inches		3.625
Area of H. P. plunger engine No. 1 in square inches		842.20
Area of each of all other plungers in square inches		843.21
Net area of H. P. piston in square inches		562.24
Net area of I. P. piston in square inches		1,651.59
Net area of L. P. piston in square inches		3,838.10
Clearance in H. P. cylinder, per cent		1.36
Clearance in I. P. cylinder, per cent		1.45
Clearance in L. P. cylinder, per cent		2.51
Diameter of steam pipe at engine in inches		8
Area of clear opening of suction valves for each plunger, square inches		560
Area of clear opening of discharge valves for each plunger, square inches		560

DESCRIPTION OF THE BOILERS.

The boilers are of the horizontal tubular type, set in brickwork and fired below the shell. They are nine (9) in number. At the time of the trial six of them had been provided with "Hawley Down Draft" furnaces and the three others were in the process of being so altered. The gases pass downward through the fire on the upper grate, over the lower grate and bridgewall, thence along the shell to the back end, returning through the tubes, after which they pass back over the top of the shell to a horizontal iron flue which leads to the chimney. The principal dimensions of the boilers are as follows:

Number of boilers		9
Diameter of shell in inches		62
Length of shell in feet		20
Number of tubes		49
Diameter of tubes in inches		4
Length of tubes in feet		20
Water heating surface in square feet	Shell and heads	188
	Tubes	980
	"Hawley" upper grate	60
	Total	1,228
Area of upper grate (Hawley Furnace), square feet		22
Area of lower grate in square feet		22
Area of chimney in square feet		38.5
Height of chimney in feet		125

During the trial four boilers were used, designated No. 1, No. 2, No. 3 and No. 7.

CONDUCT OF THE TRIAL.

The three engines were subjected to trial simultaneously. They had been in continuous service for about five months, and the trial conditions differed from those of normal service only so far as the weighing of the feed water required. At times it was found necessary to throttle the discharge mains, in order to maintain the contract head. No means existed for ascertaining the slip of the pumps. Hence the volume of water pumped was measured by the displacement of the plungers, each of which was carefully measured. In the results given no allowance has been made for slip.

The pressure in the discharge pipe was measured by a gauge at each engine, the connection being throttled so as to leave a slight vibration to the pointer. These gauges were tested both before and after the trial. The level of the water in the well was measured by a copper float and rod, the latter being graduated in pounds and tenths so as to give directly the pressure due the elevation of the discharge gauge above the water in the well. This reading was verified.

During the trial no leakage occurred at the plungers. The feed water was measured by weighing. Two platform scales were placed on an elevated platform, each carrying an iron tank of one thousand pounds capacity. Below them was a third tank from which an independent feed pump drew the water. Each scale was accurately balanced with its empty tank before the trial. In operation these tanks were filled alternately until the beam tipped at 1,000 pounds, and were discharged as required into the lower tank. The scales were tested especially for the trial by the City Sealer of Weights and Measures and found correct. Each entry in the feed water log represents therefore one thousand pounds. The feed water was obtained from the feed pumps on the main engines and led by a pipe to the weighing tanks. Here the valves were handled by an employe of the station in the presence of the observer. This observer had no other duty than to record the feed water.

The temperature of the feed water was taken at the tanks and also as it entered the boilers. The thermometer in the feed pipe at boiler No. 7 became deranged shortly before the trial began and its reading has been neglected.

In calculating the heat units in the steam the temperature of the feed water at the weighing tanks has been employed.

Since the feed water passed through almost identically the same pipes as it does in normal service, no occasion exists for estimating frictional or other resistances excepting the theoretical work of injecting the feed water into the boiler. This work is deducted from the gross work of the pumps. The independent feed pump employed during the trial obtained steam from boiler No. 8, in which the pressure was kept about forty pounds lower than in the other boilers.

The coal burned was Hocking Valley bituminous coal. It was weighed in cars; the net weight being nominally 2,000 pounds in each car. A slight correction was found necessary in the tare and was applied.

The quality of the steam was measured at intervals of three hours by a throttling calorimeter of Prof. R. C. Carpenter's latest design. The instrument was located near the throttle valve of Engines No. 1 and No. 2. Engine No. 3 was assumed to have the same quality of steam as engine No. 1, since both took steam from the same pipe. A single trial in the vertical steam pipe over boiler No. 7 indicated one-quater of one per cent. less moisture in steam than at engine No. 2.

The steam gauges on the boilers and also those on the engines were tested before the trial.

All gauges, counters and thermometers were read every fifteen minutes.

The duration of the trial was forty-eight (48) hours, the observers being divided into two watches of twelve hours each. In addition to the trial observers, the Edward P. Allis Company had a number of observers sufficient to keep a complete set of independent logs.

On account of the multiplicity of cylinders and the length of the trial, it was deemed advisable to take no indicator diagrams during the Duty Trial.

The trial commenced at 12, noon, May 19. The condition of the fires was observed; the gauges were read; the height of water in each boiler was determined by a string on the glass gauge, and the height of water in the lower tank noted. In the engine-room all the counters were read simultaneously. The trial was closed in the same way at 12, noon, May 21. During the trial four boilers were used. A higher evaporative efficiency could doubtless be obtained by using five or six boilers with the same total grate area.

RESULTS OF DUTY TRIAL.

1.	Duration of trial in hours	48

AVERAGE PRESSURES.

2.	Pressure at boilers by gauge	120.07
3.	Atmospheric pressure in lbs. per square inch	14.47
4.	Absolute pressure at boilers	134.54

		Engine No. 1.	Engine No. 2.	Engine No. 3.
5.	Pressure at engines by gauge	119.8	120.	119.9
6.	Pressure in first receiver by gauge	24.3	25.4	22.9
7.	Pressure in second receiver, inches mercury	3.12	1.46	2.86
8.	Vacuum by gauge	26.59	26.54	26.66
9.	Pressure in discharge main, lbs. per sq. inch	40.14	41.26	42.31
10.	Pressure equivalent to elevation of gauge in discharge main above water in well	14.16	14.16	14.16
11.	Total pressure of resistance, lbs. per sq. inch	54.30	55.42	56.47
12.	Head equivalent to total resistance, feet	125.27	127.86	130.28

13.	Mean head for all engines (37) ÷ (32)	127.79
14.	Head of feed water equivalent to boiler pressure feet	279.05
15.	Greatest velocity of steam in steam pipe, feet per second	27.
16.	Difference of pressure required to produce greatest velocity of steam in pipe, lbs. per square inch	0.024

AVERAGE TEMPERATURES.

17.	Temperature of water pumped, Fahr	46.7
18.	Temperature of feed water at tanks, Fahr	102.9
19.	Temperature of feed water entering boilers, Fahr	102.
20.	Temperature of engine-room, Fahr	78.

FEED WATER.

21.	Feed water in 48 hours, lbs	657,120.
22.	Steam wasted by calorimeter, lbs	242.
23.	Feed water used by engines in 48 hours, lbs	656,878.
24.	Feed water used by engines per hour, lbs	1,368.27

CAPACITY.

		Eng. No. 1.	Eng. No. 2.	Eng. No. 3.
25.	Revolutions in 48 hours	47,298.	46,456.	46,198.
26.	Revolutions per minute	16.42	16.13	16.04
27.	Gallons in 48 hours	31,064,562.	30,523,800.	30,354,336.
28.	Gallons in 24 hours	15,532,281.	15,261,900.	15,177,168.
29.	Pounds in 48 hours	259,192,000.	254,680,700.	253,266,600.

30.	Aggregate revolutions in 48 hours	139,952.
31.	Aggregate gallons in 48 hours	91,942,698.
32.	Aggregate lbs. in 48 hours	767,139,300.
33.	Mean gal. in 24 hours per engine	15,323,783.
34.	Mean piston speed of all engines, ft. per minute	161.98
35.	Weight of one cubic ft. of water at 46.7 deg. Fahr	62.415

WORK.

		Engine No. 1.	Engine No. 2.	Engine No. 3.
36.	Work delivered in 48 hours, ft. lbs	32,470,945,000.	32,563,910,000.	32,996,590,000.

37.	Aggregate work delivered in 48 hours, ft. lbs	98,031,445,000.
38.	Work of injecting feed water into boilers, ft. lbs	183,302,500.
39.	Net aggregate work delivered in 48 hours, ft. lbs	97,848,142,500.
40.	Aggregate delivered horse power	1,031.47
41.	Feed water per delivered horse power per hour, lbs	13.267

CALORIMETER.

42.	Area of steam nozzle in square inches			0.01227
		Boiler No. 7.	Engine No. 1.	Engine No. 2.
43.	Gauge pressure	120.00	120.6	120.25
44.	Atmospheric pressure, lbs. per square inch	14.48	14.47	14.47
45.	Absolute pressure	134.48	135.07	134.72
46.	Duration of flow in minutes	10.	80.	80.5
47.	Pressure in calorimeter in inches of mercury	2.6	2.52	2.5
48.	Temperature in calorimeter, Fahr	279.	278.5	274.1
49.	Steam discharged, lbs	14.14	113.64	114.03
50.	Moisture in steam, per cent	1.23	1.24	1.48
51.	Aggregate steam discharged, lbs			241.84
52.	Moisture in steam, per cent. Mean of all engines, engine No. 3 using same steam as engine No. 1			1.32

BRITISH THERMAL UNITS USED BY ENGINES.

53.	Per pound of dry steam at 134.54 lbs. absolute above zero Fahr	1,220.597
54.	Per pound of entrained water in steam at 134.54 lbs. absolute above zero Fahr	353.782
55.	Per pound of water at 102.9 deg. above zero Fahr	103.00
56.	Per pound of steam used by engines	1,106.33
57.	B. T. U. used by engines in 48 hours	726,721,666.
58.	B. T. U. used by engines per hour	15,140,030.
59.	B. T. U. used by engines per minute	252,334.
60.	B. T. U. per delivered horse-power per minute	244.6

COMBUSTION.

61.	Coal burned in 48 hours, lbs	82,906.
62.	Ashes in 48 hours, lbs	6,968.
63.	Combustible burned in 48 hrs., lbs	75,938.
64.	Per cent. of ash	8.4
65.	Coal burned per hour, lbs	1,727.20
66.	Combustible burned per hour, lbs	1,582.04
67.	Coal per hour per sq. ft. of upper grate (Hawley furnace), lbs	19.62
68.	Combustible per hour per sq. ft. of upper grate, lbs	17.97
69.	Coal per hour per sq. ft. of water heating surface, lbs	0.3516
70.	Combustible per hour per sq. ft. of water heating surface, lbs.	0.3221

EVAPORATION.

71.	Feed water in 48 hours, lbs	657,120.
72.	Feed water per hour, lbs	13,690.
73.	Feed water per pound of coal, lbs	7.726
74.	Feed water per pound of combustible, lbs	8.653
75.	Feed water per hour per sq. ft. of water heating surface, lbs	2.787
76.	Evaporation factor	1.145
77.	Equivalent evaporation from and at 212° per lb. of coal, lbs	9.075
78.	Equivalent evaporation from and at 212° per lb. combustible, lbs	9.907
79.	Equivalent evaporation from and at 212° per sq. ft. of water heating surface, per hour, lbs	3.191

BRITISH THERMAL UNITS SUPPLIED BY BOILERS.

80.	B. T. U. supplied in 48 hours	726,988,333.
81.	B. T. U. supplied per hour	15,145,610.
82.	B. T. U. supplied per pound of coal	8,768.82
83.	B. T. U. supplied per pound of combustible	9,573.46
84.	B. T. U. transmitted per sq. ft. of water heating surface per hour	3,083.4

DUTY.

85. **Ft. lbs. per 1,000 lbs. of Feed water (contract basis)........................148,958,000.**
86. Ft. lbs. per 1,000,000 B. T. U.. 134,643,030.
87. Ft. lbs. per 100 lbs. of bituminous coal .... 118,022,900.
88. Ft. lbs. per 100 lbs. of combustible.. 128,852,500.

The comparatively low duty per hundred pounds of coal is due mainly to the grade of fuel, but is partly owing to the fact that only four boilers out of nine were in use, thus making the evaporation per square foot of heating surface too high for the best results.

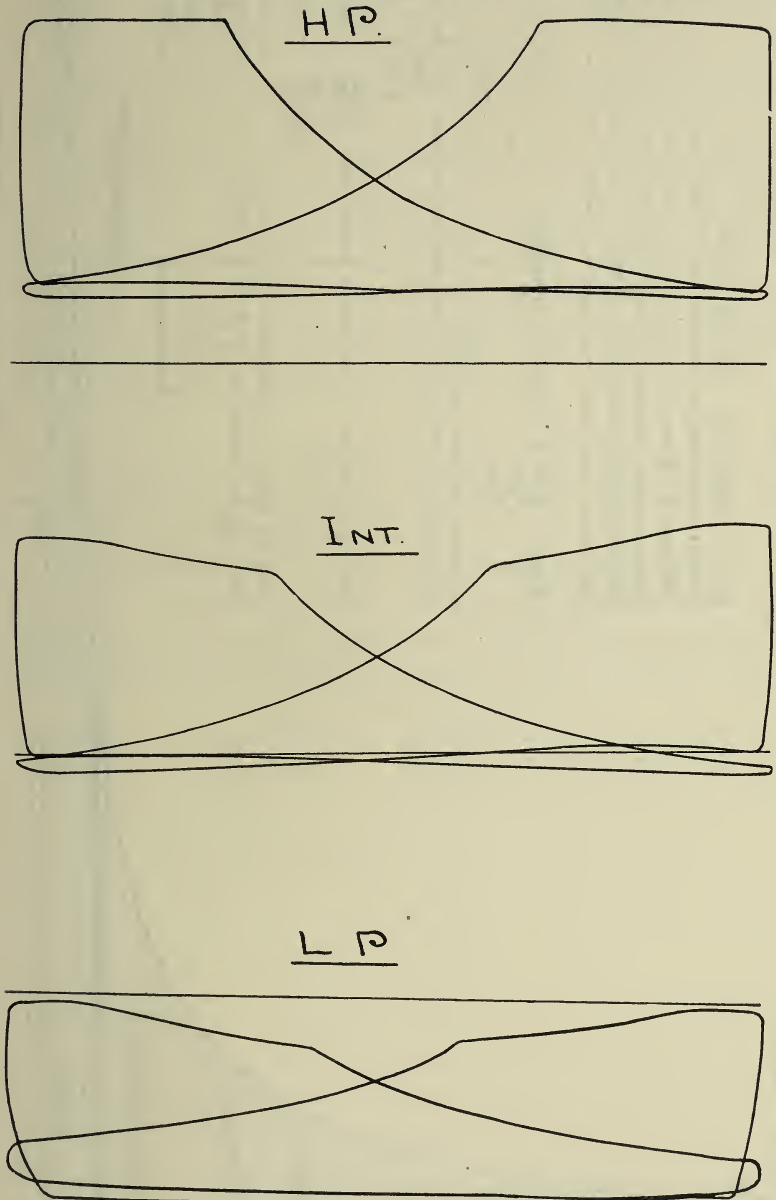
On May 22, the three engines were run simultaneously for a period of two hours and twenty-one minutes at a piston speed of 190.7 feet per minute, corresponding to a capacity of eighteen million and twenty-two thousand (18,022,000) gallons in twenty-four hours. The performance was entirely satisfactory.

FRICTION TRIAL.

On May 24, a trial of three hours' duration was made to determine the friction of the engines. During the trial seven sets of indicator diagrams were taken from each engine. The delivered horse-power is calculated from the plunger displacement and the head. Sample diagrams are submitted, together with a combined diagram, which fully illustrates the steam distribution.

RESULTS OF FRICTION TRIAL.

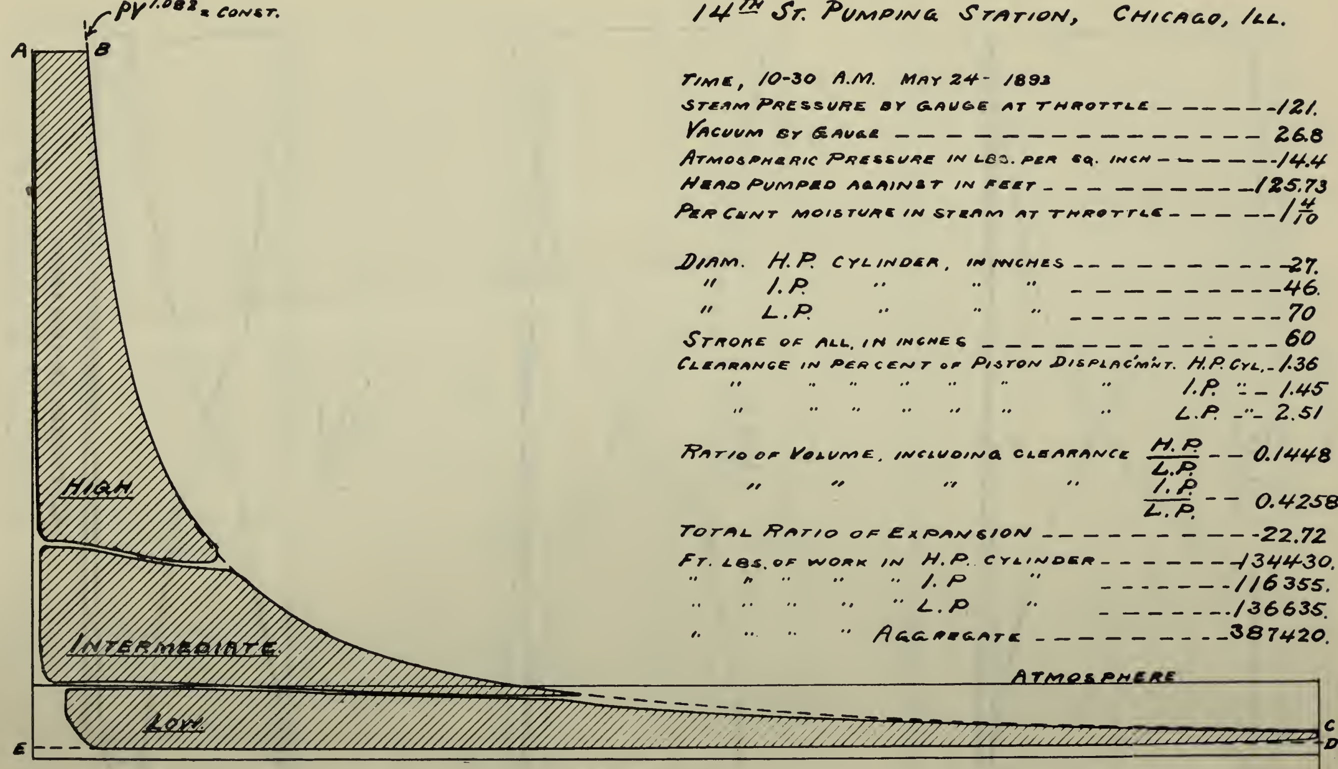
		Eng. No. 1.	Eng. No. 2.	Eng. No. 3
89.	Duration of trial, hours			3
90.	Steam pressure at engine by gauge	120.46	120.84	120.84
91.	Atmospheric pressure, lbs. per sq. inch.	14.40	14.40	14.40
92.	Absolute steam pressure	134.86	135.24	135.24
93.	Pressure in first receiver by gauge	21.88	25.07	22.42
94.	Pressure in sec. receiver in. of mercury	−3.0	−4.15	−3.92
95.	Vacuum by gauge	26.48	26.8	26.44
96.	Pressure in discharge main, lbs. per sq. inch	38.83	38.5	38.80
97.	Pressure equiv. to elevation of gauge in discharge main above water in well	14.5	14.5	14.5
98.	Total pressure of resistance, lbs. per sq. inch	53.33	53.0	53.3
99.	Head equivalent to total resistance, ft.	123.04	122.27	122.97
100.	Weight of cub. ft. water at 46 7° Fhr.			62.415
101.	Revolutions in three hours	2,950.	2,930.	2,928.
102.	Revolutions per minute	16.39	16.28	16.27
103.	Work deliv. in 3 hrs., ft. lbs.	1,989,054,700.	1,964,140,200.	1,973,904,500.
104.	Delivered horse-power	334.86	330.66	332.30
105.	Mean effective pressures. H. P.	49.90	45.62	46.68
	I. P.	12.22	14.07	13.49
	L. P.	6.583	6.708	5.993
106.	Indicated horse-power	365.04	368.14	358.11
107.	Aggregate delivered horse-power			997.82
108.	Aggregate indicated horse-power			1,091.30
109.	Mechanical efficiency			0.9143
110.	Friction, per cent			8.57
111.	Moisture in steam, per cent			1.55



INDICATOR DIAGRAMS.

INDICATOR DIAGRAM – ENGINE No. 2.

14TH ST. PUMPING STATION, CHICAGO, ILL.



TIME, 10-30 A.M. MAY 24 - 1893

STEAM PRESSURE BY GAUGE AT THROTTLE	121.
VACUUM BY GAUGE	26.8
ATMOSPHERIC PRESSURE IN LBS. PER SQ. INCH	14.4
HEAD PUMPED AGAINST IN FEET	125.73
PER CENT MOISTURE IN STEAM AT THROTTLE	$1\frac{4}{10}$
DIAM. H.P. CYLINDER, IN INCHES	27.
" I.P. " " "	46.
" L.P. " " "	70
STROKE OF ALL, IN INCHES	60
CLEARANCE IN PER CENT OF PISTON DISPLAC'M'NT. H.P. CYL.	1.36
" " " " " " " I.P. "	1.45
" " " " " " " L.P. "	2.51
RATIO OF VOLUME, INCLUDING CLEARANCE $\frac{H.P.}{L.P.}$	0.1448
" " " " $\frac{I.P.}{L.P.}$	0.4258
TOTAL RATIO OF EXPANSION	22.72
FT. LBS. OF WORK IN H.P. CYLINDER	134430.
" " " " " I.P "	116355.
" " " " " L.P "	136635.
" " " " AGGREGATE	387420.

$$\text{RATIO.}\ \frac{\text{AGGREGATE INDICATED WORK}}{\text{WORK REPRESENTED BY AREA. A,B,C,D,E,A.}} \text{ -- } 0.952$$

The indicators used were Thompson Indicators made by the American Steam Gauge Company and tested by them immediately after the trial. The mean effective pressures were corrected by the scale of correction furnished by them.

Applying the value of the mechanical efficiency to the Duty Trial the following results appear:

112.	Aggregate delivered horse-power (line 40).......................	1,031.47
113.	Mechanical efficiency (line 109)..	0.9143
114.	Aggregate indicated horse-power..	1,128.15
115.	Feed water per delivered horse-power per hour (line 41)...	15.267
116.	**Feed water per indicated horse-power per hour, pounds....................**	**12.13***
117.	B. T. U. per delivered horse-power per minute (line 60).....	244.6
118.	B. T. U. per indicated horse-power per minute..................	223.7
119.	Indicated horse-power per sq. ft. of upper grate (H. furnace)	12.82
120.	Heating surface per indicated horse-power........................	4.35

* No correction for moisture.

These engines, in both design and construction, represent the best of modern practice and their performance cannot fail to give the greatest satisfaction to the city.

Acknowledgments are due Mr. Irving H. Reynolds, of the E. P. Allis Company, Mr. John H. Lewis, representing the Contractors in the conduct of the Trial, and Mr. Charles McDonald, Chief Engineer of the Station, for courtesies and valuable assistance.

Respectfully submitted,

[Signed] ROBT. W. HUNT & CO.

[Signed] JAMES N. WARRINGTON.

COAL TESTS.

The table opposite shows the value of various kinds of coal and the cost of coal per million gallons pumped. These tests were made by the Edward P. Allis Co. and form no part of the official records, excepting that the last test (May 19-20) shows the results obtained during the official duty test.

The first test (with Anthracite coal) was made with ordinary furnace and grates, all other tests were of Bituminous coal burned in down draft furnaces.

COAL TESTS AT FOURTEENTH STREET PUMPING STATION, CHICAGO.

Date of Test	Mch 18–19.	May 6.	May 8.	May 9.	May 10.	May 11.	May 12.	May 19–20
Hours Run	24	12	12	12	12	10	12	48
Boilers Used	6	5	5	3	4	4	3	4
Square Ft. of Heating Surface	7,596	6,330	6,330	3,798	5,064	5,064	3,798	5,064
Square Ft. of Grate Surface	175	110	110	66	88	88	66	88
Average Steam Pressure	122	120.8	119.9	119	121	120	118.3	120
Temperature of Feed Water, Deg. F	109.23	112.	108.	110.	110.	110.	107.	102.
Total Water Evaporated, pounds	364,240	186,000	182,530	178,705	173,300	149,000	169,790	657,292
Total Coal Burned, pounds	43,780	24,606	30,080	20,380	25,200	17,642	20,297	80,903
Ashes, pounds	6,422	1,779	2,841	826	2,402	1,261	947	8,696
Per Cent. of Ash	14.67	7.23	9.44	4.05	9.53	7.14	4.66	10.74
Coal Per Square Ft. of Grate Per Hour	10.424	18.64	22.78	25.73	23.86	20.05	25.62	19.15
Draft Gauge, Ins. Water	....	.45	.45	.45	.4	.47	.47	.47
Actual Evap. from Temp. of Feed Water	8.319	7.56	6.068	8.768	6.877	8.5	8.36	8.136
Evaporation from and at 212°	9.55	8.69	6.98	10.08	7.908	9.77	9.64	9.413
Actual Evap. Per Lb. of Combustible	9.75	8.15	6.7	9.13	7.6	9.09	8.77	9.12
Evap. Per. Lb. of Cmbst. from and at 212°	11.2125	9.3725	7.705	10.4995	8.74	10.4535	10.0855	10.5792
Kind of Coal	Anthracite.	Shawnee.	Brazilian Nut and Slack.	New River.	Hazel Creek Screenings.	Shawnee Yo'ghiog'y.	Shawnee.	Shawnee.
Price Per Ton	$5.40	$3.40	$1.85	$3.90	$1.30	$3.40	$3.40	$3.40
Gallons of Water Pumped	45,770,432	22,860,228	22,738,928	22,976,400	22,974,432	19,234,576	23,026,912	91,942,698
Head Pumped Against	132.92	124.	120.6	117.13	114.16	117.92	118.53	127.8
Cost Per Million Gallons, Against Head	$2.59	$1.83	$1.223	$1.73	$0.713	$1.56	$1.49	$1.49
Cost Per Million Gallons, One Ft. High	$1\frac{94}{100}$cts.	$1\frac{47}{100}$cts.	$1\frac{1}{100}$cts.	$1\frac{3}{10}$cts.	$\frac{62}{100}$cts.	$1\frac{32}{100}$cts.	$1\frac{25}{100}$cts.	$1\frac{16}{100}$cts.